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DISCUSSION PAPER SERIES

No. 515

Conclusion and Practical Implications

Takahiro Fujimoto
Graduate School of Economics,
University of Tokyo, Tokyo, Japan

June, 2019

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

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CONCLUSION AND PRACTICAL IMPLICATIONS[1]

Takahiro Fujimoto*[*]

Graduate School of Economics, University of Tokyo, Tokyo, Japan

[1] This discussion paper is a reprint of the content, but not the formatting, of chapter 10 "Conclusion and Practical Implications" in Fujimoto, T. and D. A. Heller (ed.) (2018) Industries and Disasters: Building Robust and Competitive Supply Chains. Hauppauge, NY: Nova Science Publishers, pp.263-304. ISBN: 978-1-53612-905-2, Based on the Agreement Between the authors and NOVA science publishers.

[*] Corresponding Author: fujimoto@e.u-tokyo.ac.jp.

Abstract

This Chapter summaries the findings of the cases presented in this book and gives practical implications for firms that take a leading role in managing industrial supply chains. In particular, guidance is given on the ways in which supply chains can be diagnosed for vulnerabilities and the remedies that may be applied. One such countermeasure, virtual dualization, is explained in detail, as a means for achieving both supply chain robustness and competitiveness for complex products that require intense coordination in their design and production. A common theme that runs throughout the chapter is the importance of building trust among the participants in a supply chain.

Keywords

Sub-targets for final production lines, Sub-sub targets for all suppliers, Make-to-stock production, Production lead times, Dispersion, Substitution within a supplier first, RESCUE database, Detachable, Indirect transfer of design information, Special-purpose machine tools, Leading firm, Supply chain continuity, Countermeasure, Supply chain recovery assistance center, Supply chain triage, Recovery resource planning, Organizational design, Front-loading problem solving, RRP, Recovery on-the-spot first, Principle of "human rescue first, community second, production third", Rescue provisions, Preparations, Actual dualization, Detaching information, Duplicating information, transferring information, Re-embedding information, NC machine tool, CAD-CAM, Transferring design information, Evacuation drills of critical design information, Product-process configuration, Capability-oriented

1. SUMMARY OF THE BOOK AND METHODOLOGICAL/PRACTICAL IMPLICATIONS

1.1. Learning from Actual Cases

The present book described and analyzed how firms and industrial sites (*genba*) try to pursue supply chain robustness against major disasters without losing supply chain competitiveness. Chapter 1 illustrated the main themes and motivations of the book, focusing particularly on the 2011 Great East Japan (Tohoku) Earthquake and the quick recovery of most of the firms and genba in the affected areas. Chapter 2 presented a survey of the existing literature, mainly in relation to supply chain management and business continuity planning (BCP). Chapter 3 proposed key concepts and a framework for supply chain diagnosis and recovery based on our *design information flow* approach to manufacturing and supply chains.

The other chapters dealt with individual cases of disaster recovery in different settings. Chapter 4 was about on-the-spot recovery when substitutive production proved too difficult (Riken after the 2007 Chuetsu Offshore Earthquake). Chapter 5 concerned substitutive production when quick recovery of the damaged factory was impossible (1997 Aisin fire). Chapter 6 discussed a case in which the main production line was moved to a less disaster-prone location within the same area (Epson Atmix, 2011 Tohoku Earthquake). Chapter 7 broadened our view to a disaster that occurred overseas and the ensuing global supply chain crisis (Honda, Thailand, 2011 Flooding). Chapters 8 and 9 examined the capabilities, practices and principles of Toyota Motor Corporation and its group companies for supply chain robustness, focusing on actual patterns of judgments/decisions/actions in Japan following flooding in 1991 and great earthquakes that occurred in 1995, 2011, and 2016.

Methodologically, throughout this book, we only used the case study approach, partly because major disasters are rather rare events that may not fit statistical analyses, and partly because our aim is to shed light not on individual decisions and actions but rather on their patterns and sequences, which can be better grasped through case studies. Further statistical analysis will be needed in the future but, for now, this field is still at the stage of exploratory research.

1.2. Practical Implications for Leading Firms

Various practical issues emerging from the above case studies will be presented and discussed in this last chapter. Although all the suppliers within a supply chain are responsible for its robustness and resilience against disasters, we will focus mainly on the role of *supply chain leading firms*, which position themselves at the core of their supply networks, are connected to numerous suppliers and/or customers directly or indirectly, have rich managerial resources to help others in times of emergency, and are rightfully expected by the members of the supply chain to take leading roles. Large and competent final product firms, key component suppliers and chemical companies are typical examples of such supply chain leading firms.

With the role of said leading firms in mind, we will discuss the following issues (Figure 1): (1) setting *target lead times* for anti-disaster recovery; (2) supply chain *diagnosis and remedies*; (3) countermeasures against future major disasters, including quick *recovery on the spot*, *quick substitutive production* and *virtual dualization* (Fujimoto and Park 2014).

More specifically, (1) the leading firms may first establish a consensus across the supply chain by setting the ultimate goal of *supply chain continuity*, as well as the sub-goals of setting lead times for restarting production in downstream (e.g., final product assembly) processes and production recovery targets for upstream suppliers.

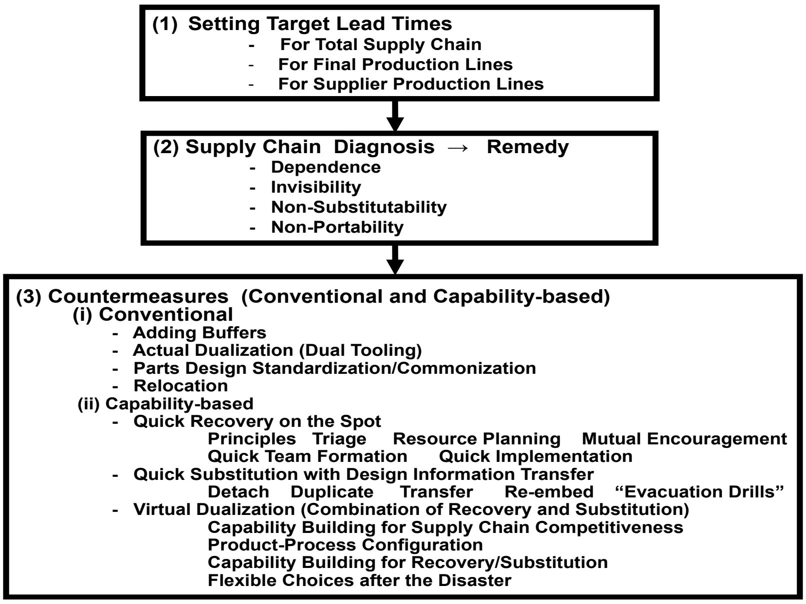

Figure 1. Practical implications for leading firms in a supply chain.

(2) The leading firms preparing for future major disasters—particularly the final product producers, such as car manufacturers—must carry out *supply chain diagnoses* for the entire supply chain and continually update them. As suggested in Chapter 3 and in the case studies, they should pay particular attention to vulnerability factors like supply source *dependenc*e, substitutability of each item, suppliers' *invisibility*, as well as design information *non-substitutability* and *non-portability*. Once any weak points are identified, the leading firms must try to make them more robust before the next disaster strikes.

(3) By working together with their suppliers, the leading firms will need to build capabilities for quick recovery of the damaged nodes and links and continuity of the total supply chain/network. These measures will include not only traditional ones, such as (i) *adding buffer inventories*, (ii) product redesigning in order to use more *standardized/common parts*, (iii) *production line dualization* (duplication of identical design information flows), and (iv) *moving plants* away from seemingly disaster-prone locations, but also (v) capability building for *quick on-the-spot recovery* of the damaged lines and (vi) capability building for *quick start of substitutive production* with design information transfer, as well as (vii) *virtual dualization* of the suppliers' production networks, as a comprehensive strategy combining quick recovery and quick substitution.

The key point to be considered when dealing with diagnoses and countermeasures is that the overall goals to be achieved in a crisis situation should be shared across all the firms and the entire supply chain, as stated at the beginning of this book—e.g., the awareness that the 2011 Tohoku Earthquake was "the first huge disaster to affect a wide region in an industrialized country that is competing globally". In other words, changing a production system solely in response to disasters while sacrificing capabilities against intense global competition, particularly in the post-Cold War era of the 21st century, could result in deterioration of competitiveness and endanger the very existence of the companies and genba in question even before the next big disaster strikes.

1.3. Do Kaizen Capabilities Work in Recovering from Major Disasters?

A pattern often observed in cases of unsuccessful approaches is that firms tend to focus too much on their competitive survival, thus neglecting effective preparation for future disasters and, at the same time, they are so deeply affected by actual disasters that they become trapped in a "disaster-countermeasures-first" mentality, partly because of their aforementioned unpreparedness. Such vicious cycles of unpreparedness and overreaction should clearly be avoided.

Conversely, supply chain robustness and resilience require virtuous cycles of preparedness, quick countermeasures, and continuous capability building before and after specific major disasters, so that competitiveness and robustness can be achieved in a more balanced way. This *capability-orientated approach* to disaster recovery management—the main argument put forward in this book—is founded on organizational capabilities, rather than buffers, to simultaneously pursue supply chain competitiveness and robustness.

Our case studies on capability building in leading firms with effective anti-disaster rescue/recovery/restoration approaches, such as Toyota (see Chapter 8), suggest that continuously strengthening genba's *kaizen capabilities* can lead to successful quick response in case of unprecedented disasters. Some academic and practical arguments support the idea that capabilities for frequent, small improvements (e.g., incremental innovations) differ from those needed for infrequent, big changes. Nonetheless, as far as anti-disaster supply chain robustness is concerned, we believe that these two capabilities are in fact compatible mainly because, if we look at the details of real cases, major recovery and restoration projects are often a collection of successive, small problem-solving activities. In other words, kaizen may be regarded as a series of tiny but frequent disasters.

Furthermore, the aforementioned continuous building of anti-disaster capabilities in a scenario of considerable uncertainty is nothing but the manifestation of the evolutionary capabilities of leading firms and genba, such as Toyota and its major suppliers (Fujimoto 1999).

2. Targets and Diagnoses

2.1. Sharing Lead Time Targets

Let us now look at each of the practical implications emerging from the case studies. First, the leading firms must estimate the target lead times for the recovery of the total supply chain and of individual manufacturing sites. It is worth underlining here that continuity and recovery of the whole supply chain and recovery of individual production lines for a given product are not equivalent. Hence, a hierarchy of targets must be established, specifically: (i) overall target of the supply chain; (ii) sub-targets for final production lines of the product in question; (iii) sub-sub targets for all suppliers of the product in question.

Overall Target of the Supply Chain

In this case, at least two possibilities have to be considered. First, if the final product is important for many customers and is produced to stock, it is reasonable to set the target of *supply chain continuity*, with supply stoppage time for this item equal to zero. Second, if the product in question is made to order, without any back-up inventories, then delays are inevitable, so the target lead time to restart and complete the delayed order is the number of days that the customer can wait without cancellations or major penalties ($\hat{W}_i$).

Sub-Targets for Final Production Lines of the Product in Question

Let us imagine the worst-case scenario, e.g., the final producer of an item—for instance, a car maker producing model *i*—was heavily damaged and all the material/WIP/product inventories in its factory were destroyed. The target lead times for final production restart will vary depending on whether the item is produced by make to stock or make to order system.

In the case of make-to-stock production, the target recovery lead time, T*, or the elapsed time between destruction by the disaster and restart of the entire production line of the affected final product *i* should be equal to, or shorter than, the estimated number of inventory days of the intact stock of product *i* in the downstream distribution channel ($\tilde{I}_i$) minus total production lead time needed for the firm to complete the first lot after the restart ($\tilde{L}_i$). That is, $T_i^* \leqq \tilde{I}_i - \tilde{L}_i$. Transportation/distribution lead times are ignored for simplicity.

Note here that the abovementioned inequality can be re-written as $T_i^* + \tilde{L}_I \leqq \tilde{I}_i$, which implies that the minimum days of anti-disaster inventories can be shorter if the firm's recovery lead times and/or production lead times are shorter as a result of capability-building in normal time. In other words, if the manufacturing sites accumulate capabilities for both normal production and recovery from disruptions, it can reduce anti-disaster buffers accordingly. This is why we advocate the "capability first, buffer next" principle in this book.[2]

SUB-Sub Targets for All Suppliers of the Product in Question

The target lead time to resume production for the *k*-th tier supplier of part *j* for product *i*, which was damaged by the disaster, is t_{ijk}^*. If the target recovery lead time of the final product producer mentioned above is T_i^*, then the production restart target for the damaged tier-1 (first tier) supplier (ij1) of parts *j* of product *i* would be $t_{ij1}^* \leqq T_i^* + \tilde{I}_{ij1} - \tilde{L}_{ij1}$, in which $\tilde{I}_{ij1}$ is the estimated inventory days of parts *j* held by the final producer of product *i*, and L_{ij1} is the supplier's estimated production and delivery lead time for parts *j*, assuming that all of the supplier ij1's inventories were destroyed and that parts *j* were delivered to the first station of the final production process, which is the worst-case scenario where $\tilde{I}_{ij1}$ is small and $\tilde{L}_{ij1}$ is large.[3]

All of these inequalities indicate that information on the target recovery lead times (T_i^* *and all* t_{ijk}^*) should be shared not only between direct customers and suppliers (t_{ijk}^* *and* t_{ijk-1}^* by k-th and k-

[2] The estimated number of inventory days is $\tilde{I}_i = \tilde{S}_i / \tilde{D}_i$, where $\tilde{S}_i$ is the estimated amount of inventory of *i* in the intact distribution channel and $\tilde{D}_i$ is the estimated demand per day for *i*. $\tilde{L}_i$ is the estimated total production lead time for this firm. If demand for the product in question grows in times of disaster (e.g., rescue materials or medical goods), then the estimation of post-disaster daily demand $\tilde{D}_i$ should be increased and that of inventory days $\tilde{I}_i$ should be shortened accordingly.
Conversely, if the material/WIP/product inventories in the plant (and the final production lines) survive the disaster, then these can simply be added to the estimated inventory, $\tilde{S}_i$, through which the factory can buy additional lead time for recovery (e.g., longer T_i^*) in the form of longer $\tilde{I}_I$, as well as shorter $\tilde{L}_I$ because the line can complete the first lot immediately after its restart by using undamaged work-in-process on the spot. However, when making a firm's ant-disaster plans, their assumption should be the abovementioned worst case of the complete inventory destructions rather than this lucky case.
If a customized product is made to order, e.g., without any product inventory, then the target lead time for restarting final production is $T_i^* \leqq \tilde{W}_i - \tilde{L}_{MAXi}$, where $\hat{W}_i$ is the estimated waiting time or delay that customers may accept and $\tilde{L}_{MAXi}$ is the estimated maximum production lead time for completing the order. Here it may be best to consider the worst-case scenario, in which, when the disaster struck, the manufacturer was in the middle of final production of the longest-lead-time item and all the half-finished products were entirely destroyed. In such a case, $\tilde{L}_{MAXi}$ is simply the final production lead time of the longest-lead-time item. If the calculated T_i^* is zero or negative, this is not a realistic goal, so the firm may need to negotiate with the customers and emergency clauses should be included in contracts to deal with situations arising from natural disasters.
Hence, depending upon the type of production, the target lead times for final production completion (T_i^*) should take into account such factors as estimated product inventory levels ($\tilde{S}_i$), estimated demand in times of disaster ($\tilde{D}_i$), delays that customers may accept ($\hat{W}_I$), and maximum final production lead times ($\tilde{L}_i$). A firm may also want to consider possible reduction of said lead times ($\tilde{A}_i$).

[3] Likewise, if the tier-2 (second tier) supplier of a sub-parts of part *j*, ij2, is also damaged by the disaster, then the target recovery lead time is $t_{ij2}^* \leqq t_{ij1}^* + \tilde{I}_{ij2} - \tilde{L}_{ij2} = T_i^* + \tilde{I}_{ij1} - \tilde{L}_{ij1} + \tilde{I}_{ij2} - \tilde{L}_{ij2}$, with a similar worst-case assumption that $\tilde{I}_{ij2}$ is small and $\tilde{L}_{ij2}$ is large. The target recovery lead time for the destroyed tier k supplier is calculated in a similar way: $t_{ijk}^* \leqq T_i^* + \tilde{I}_{ij1} - \tilde{L}_{ij1} + \ldots + \tilde{I}_{ijk} - \tilde{L}_{ijk}$.

1st suppliers) but also by indirect ones in the entire supply chain (e.g., T_i* *and* t_{ijk}^* between the final product manufacturer and any of the lower tier suppliers jk) wherever necessary, as anything can happen at any point of the chain in time of disasters.[4]

It is worth noting that the destroyed tier-k supplier will be able to afford longer recovery lead times t_{ijk}^* if the production lead times of all layers, $\tilde{L}_{ij1} + \cdots + \tilde{L}_{ijk}$ are shorter, even when the finished goods inventories of all layers $\tilde{I}_{ij1} + \cdots + \tilde{I}_{ijk}$ are relatively small. This is the strength in supply chain recovery of Toyota-style just-in-time (JIT) manufacturers, which pursue shorter lead times through "good flows of design information."

The basic calculations suggested above to set supply chain recovery goals indicate that the likelihood of achieving the overall goal of supply chain continuity (minimizing delays) will be increased by two methods repeatedly mentioned in this book: adding buffer inventories ($\tilde{I}_{ijk}$) between firms and/or reducing production lead times ($\tilde{L}_{ijk}$) of the firms along the supply chain. Once again, we believe that shortening lead times can simultaneously enhance the supply chain's competitiveness and robustness, whereas adding buffers does enhance robustness but often by sacrificing competitiveness.

Moreover, operations of the JIT type of course involve maintaining certain levels of final product inventories. For example, Toyota usually keeps about a month of product inventories in its distribution system in the US. Past experiences with major disasters in Japan show that the target lead times for production recovery of manufacturers and supplies are typically two or three weeks. In any case, all the firms involved in the supply chain for a given product will need to reach a consensus on the target lead times for the whole supply chain as well as for each individual supplier.

2.2. Supply Chain Diagnosis and Remedies

Once the goals of flow continuity, minimum stoppage, and target recovery lead times are set for the entire supply chain, its leading firms should continually perform diagnoses to identify supply chain weaknesses and eliminate or reduce them before the next major disaster occurs. In Chapter 3 we pointed out that there are at least four possible vulnerabilities of a given supply chain: dependence, non-substitutability, invisibility and non-portability. Whenever downstream firms along the supply chain (e.g., car manufacturers) single out certain parts or materials that they buy from their upstream suppliers as "weak" in relation to the above four criteria, they should concentrate their anti-disaster preparations and improvements on such critical items. As explained in Chapter 9, Toyota created a comprehensive supply chain database after the 2011 Great East Japan Earthquake to detect "risk items" that would be identified from the points of view of single site supply (dependence) and design/process/material specificity (non-substitutability).

Keeping in mind the importance of detecting and strengthening weak points/links in the supply chain, let us now discuss our findings concerning these four aspects of supply chain diagnosis and possible remedies.

Dependence/Dispersion

After recent major earthquakes, Japan's automobile industry has had to deal with frequent cases of overdependence of a buyer firm on a single supplier, particularly second- or lower-tier suppliers

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[4] The above calculation is based on a simplified worst-case scenario, but we can make more realistic assumptions by looking at the actual paths of part and sub-parts *jk* to product *i*. Furthermore, while the inventory days ($\tilde{I}_{ijk}$) may include both finished goods inventories of the tier k supplier and material inventories of the tier k-1 supplier (e.g., the customer), the former may have to be carefully excluded from this calculation if it can be reasonably predicted that supplier k's inventories will be destroyed together with its production lines.

providing specific items—the so-called “diamond-shaped structure” of a supply chain where a critical, single-source supplier is at the lower or lowest tier of the supplier chain (Chapter 3). Examples of such situations include the cases of Riken in 2007 (Chapter 4), Renesas in 2011 and Aisin Kyushu in 2016 (Chapter 8).

Such dependence tends to occur in the following circumstances. First, when the parts in question are customer-product-specific, and especially when such products are domestic-product-specific, their demand tends to be limited, making multiple sourcing more difficult. Second, when their production technologies require expensive special equipment, their minimum efficient scales tend to increase and often exceed demand, making single sourcing of such items economically preferable. Third, if the parts are high-value-added compact components with relatively low transportation costs (e.g., electronic parts and devices), their suppliers will find it more economical to concentrate their production base and ship/export the items from one factory.

When a customer company identifies such supply chain dependence, it may simply ask its suppliers to geographically disperse their production lines not only domestically but also internationally. As repeatedly argued in this book, provided that this structural change is compatible with the competitiveness of the genba sites and of the supply chain, it should indeed be implemented, since it may reduce dependence and improve competitiveness at the same time.

If, however, the current diamond-shaped structure is a result of sound strategy pursued by the suppliers amidst global competition, the customer firms should be careful not to impose this change in fear of overdependence, as supply chain competitiveness may be greatly reduced. The leading firms (e.g., the automobile manufacturer) will need to work together with their suppliers and adjust the features of the supply chain to ensure that production dispersion will not mean sacrificing competitiveness.

For example, an automobile firm may modify its product designs to adopt more common parts in its different product models domestically and globally, expand overall demand quantities and make dispersion of production lines economically justifiable. Yet, it must be very careful to make sure that doing so does not to destroy its models’ product integrity and differentiation (Clark and Fujimoto 1990). The leader firm may also try to implement joint process innovations with its suppliers, so as to make their production equipment more compact, inexpensive, and be able to operate with lower minimum efficient scales, thereby ensuring that multiple production lines of smaller size will be competitive.

To sum up, in order to reduce a supply chain’s dependence while maintaining and improving its competitiveness, upstream as well as downstream firms may need to collaborate and introduce changes to achieve both of the above goals at the same time, rather than unilaterally multiplying supply sources due to fear of supply chain dependence.

Non-Substitutability/Substitutability

The problem of non-substitutability tends to occur when the production technologies and know-how are unique to a certain supplier, but such supplier-specific processes tend to be the very source of competitiveness. So, it may not be wise for the customer firm to hastily try to make the supplier’s product-process design information substitutable, as this is likely to jeopardize the latter’s competitive advantage, reducing its motivation to continue investing in its technical competences. Thus, the issue of non-substitutability is often inseparable from the issue of commitment and trust on the part of the supplier, which is an essential element to achieve supply chain competitiveness in the case of complex and architecturally integral products consisting of many product-specific parts, such as highly functional cars.

One way to increase substitutability of production lines without decreasing the supplier's commitment is for the buyer company to clearly state that, should the situation arise, substitutive production will be assigned to another production line of the same supplier, as opposed to another supplier. In this case, if the supplier in question, producing part X in its factory A, believes that it is capable of commencing substitutive production of X in its factory B if A is damaged or destroyed, it will be reassured that no orders will be lost. The supplier will need to transfer technologies and know-how from factory A to B, but it will be able to preserve its distinctive capabilities. In actual fact, this principle of "substitution within a supplier first" has been consistently followed by Toyota, according to Chapter 8 of this book.

When the demand for part X is smaller, it may be best to try and simultaneously increase substitutability and reduce dependence. For example, the automobile firm that buys part X from supplier Z may work with Z to (a) increase purchasing volumes through parts commonization, (b) make the equipment for producing X more compact and efficient, and (c) facilitate supplier Z's decision to have two lines in two different regions, making items that are similar to, if not the same as, part X. At the same time, the automobile firm may tell the supplier about its principle of "substitution within a supplier first", support the supplier's capability building in normal times, and then consistently implement this policy whenever disasters actually occur.

In summary, as seen in the case of supply chain dependence, measures taken to improve the substitutability of parts production should be compatible with capability building and competitive improvements that target the total supply chain, since such actions are necessary in the age of intense global competition. A related issue not to be overlooked is that of mutual commitment and trust between a product firm and its suppliers, as well as the communities around them, because production substitution may lead to loss of employment opportunities for the local population.

Invisibility/Visibility

In recent years, the introduction of information technology (ICT) has played a crucial role in improving the visibility of the entire supply chain. Toyota Motor Corporation, for example, established a supply chain database of nearly all its parts, including about 4,000 items, 13,000 suppliers and 30,000 sites in Japan (Chapter 9). This extensive database obviously needs constant updating and Toyota uses the cloud computing services of an external ICT vendor to maintain it.

It should be noted that Toyota has about 400 first-tier suppliers in Japan, which means that the vast majority of its lower-tier suppliers voluntarily provided information about their business, although they did not have any direct contract with Toyota and, therefore, no obligation to disclose their data. Thus, the database was set up thanks to a combination of advanced information technologies and inter-firm relationships based on human trust. Toyota also declared that it intends to use the database only for disaster preparations/countermeasures and that it will never abuse its suppliers by using information contained in the database in price negotiations.

This database dramatically enhances the visibility of the total supply chain. For example, the author happened to have a meeting with a Toyota manager in September 2015, when heavy rains caused the flooding of the Kinu River mainly in Ibaraki Prefecture, to the north of Tokyo. The manager said: "This flooding is awful, but one consolation is that our suppliers' sites narrowly escaped being submerged." He then took out his smartphone that was displaying a real-time map of the flooded area with the locations of some 30,000 sites, all of which were certainly above water.

Real-time detection of damaged/intact supplier sites was impossible back in 2011 and the database also allows instant visualization of the total supply chain of each item (Chapter 9).

Supply chain visibility is a vital condition for quick recovery of damaged suppliers, particularly in the aftermath of major disasters affecting very wide areas, like the 2011 Tohoku Earthquake. If the affected suppliers cannot be identified quickly, no matter how outstanding the company's recovery assistance capabilities are, the damaged sites cannot be reached in the first place. In fact, one major problem that Toyota had in 2011 was that its initial rescue and recovery actions were significantly delayed due to the invisibility of lower-tier suppliers. However, thanks to its "evolutionary capability" (Fujimoto, 1999) for building additional capabilities based on unexpected events such as disasters, the company moved quickly and implemented the abovementioned database, called RESCUE. For now, it mostly covers Toyota's domestic supply chain, so the next step would be to expand it globally.

Additionally, the creation of the RESCUE database made not only lower-tier suppliers visible to Toyota but also Toyota itself visible to these upstream suppliers, as many of them did not originally know that what they produced was used for the manufacturing of Toyota products. It is reasonable to infer that realizing that they were part of Toyota's supply chain and that the company may come to help them in case of future disasters increased their motivation and commitment to stay competitive, so that they would continue to be selected by this supply chain. Hence, such efforts made to enhance supply chain robustness will have also contributed to supply chain competitiveness.

Non-Portability/Portability

Portability of design information in times of disaster differs depending on the product/process. Some of the product-specific design information can be detached from the damaged production lines relatively easily, whereas in other cases it "sticks" to the equipment and it is difficult to move elsewhere.

In the case of flexible production lines, like machining processes that use numerical control (NC) or general-purpose machine tools, the product-specific design information, such as NC programs and operators' skills, may be moved from the damaged machine to another machine with no great difficulty. In stamping and molding operations, also, the product-specific design information is embedded in molds and dies that are detachable from the main equipment, so it is portable or directly transferable, in this sense. In the above cases, it is usually possible to set up a substitutive production line relatively quickly by removing from the damaged equipment the dies, tools, jigs, and programs containing the product design information. These will then be transferred to another generic production line, adjustments and alignment to the alternative equipment will be performed, and once test operations are completed production can be started on the new line.

Even when the dies and molds are completely destroyed, as shown in Chapter 3 (Figure 4), it might be possible to move upstream along the engineering chain, obtain the original product or process design information and quickly create replacement dies and molds for on-the-spot recovery or substitutive production. We may call this indirect transfer of design information via upstream product development resources.

As for special-purpose machine tools, the product-specific design information is embedded in the main body of the hardware itself so that, if the machines are destroyed, so is the product design information. However, the work done by special-purpose machines may be replaced by NC or general-purpose machines, although their speed will be slower and costs will be higher. That is, the product-specific design information embedded in the machines' hardware may be indirectly transferred to NC programs or versatile operators' skills for substitutive production by means of NC or general-purpose machines. One such example was the Aisin Seiki fire (Chapter 5; Nishiguchi & Beaudet 1999), where the tools recovered from the ashes were sent with the original part drawings to several many machining suppliers. Skilled workers at these suppliers read the drawings and reproduced the parts, which thus had identical product design information.

Unlike in the above cases of ordinary machining and forming operations, design information may be less portable in process industries that require precise operations, such as high-performance functional chemicals, in which adjusting the "recipe" to each individual piece of equipment is difficult. Precise process industries also differ from forming-machining-assembly industries in that the product design information is not provided by engineering designers but by the materials and catalysts themselves. In a sense, the latter may be regarded as a self-organizing micro-assembly process, in which human intervention is only indirect—opening/closing valves, controlling temperature/pressure, and governing timing/volume of inputs and outputs for the chemical reactions. Because of this indirect control over the design information, adjusting the recipe to the new equipment may take a long time, which is also the case in scale-up jobs during normal production.

Even so, following the 2011 Tohoku Earthquake, many chemical plants in the affected areas started substitutive production fairly quickly by transferring and adjusting the recipe information to other plants outside the Tohoku district (e.g., Kaneka's Kashima vinyl plant, Chapter 1).

Portability of design information is also an issue in operations relying on extremely precise control or alignment, for instance in the preprocessing of semiconductors, like the microcontrollers and ASICs manufactured at the Naka plant of Renesas Electronics (Chapter 1). Since advanced semiconductor preprocessing requires alignment precision on a sub-micron or nanometer scale, product-specific circuit design information embedded in the masks tends to "stick" to the equipment (von Hippel, 1994). Hence, readjusting both the damaged original equipment and the replacement machinery was expected to be a very difficult task and the recovery lead times of the Naka plant were initially estimated at several months to a year. Nevertheless, about half of the items were moved to substitutive production sites in other regions of Japan—showing a certain level of design information portability— and, also thanks to effective inter-firm help by customer companies, the resumption of Naka's production was actually achieved within about three months. And yet even so, microcontrollers had the longest recovery lead times and the greatest impact on a wide range of industries worldwide in the aftermath of the 2011 Tohoku Earthquake.

To sum up, products characterized by extremely high levels of product-process precision and adjustment, such as highly functional chemicals and advanced semiconductors, should be watched with special attention and steps should be taken to improve their portability in normal times.

3. Countermeasures and Preparations

3.1. Combining "Recovery on the Spot" and "Substitutive Production"

When the supply chain's leading firms (i) set and share their goals concerning total supply chain continuity and recovery lead times and (ii) continually conduct supply chain diagnoses to identify weak nodes/links and risky items, while also concentrating their capability building efforts on *kaizen* improvements during normal production, the next challenge for the supply chain is to pull together and achieve complete recovery if and when a major disaster strikes its industry, firms, and sites.

Traditional countermeasures—like adding buffer inventories, switching to standard/common parts, duplicating production lines or moving lines elsewhere—can be adopted depending upon the situation, but they have to be compatible with the goal of improving supply chain competitiveness in the long run. In other words, if adding buffers results in significant competitive disadvantages in terms of lead times, if dualization of production for every item leads to below-minimum-efficient-scale operations, and if standardization/commonization of parts design decreases product design quality, such traditional countermeasures may not be advisable. It is worth noting that a number of firms in Toyota's supply chain moved some of their production facilities from the central part of Japan, a seemingly more earthquake-prone region, to Tohoku (North-East) and Kyushu (South-West) but, in a twist of fate, both were the areas struck by big earthquakes.

In any case, capability building efforts aimed at reducing dependence, non-substitutability, invisibility, and non-portability require the active collaboration of the firms and sites involved in the supply chain. At Toyota, for example, the order of priority concerning permanent countermeasures for supply chain robustness is said to be: (i) dispersing production sites (reducing dependency), (ii) disaster prevention (*gensai* in Japanese) at each site, (iii) adopting more common/standard parts, (iv) adding inventories (but only for a small number of items), in this order.

By combining individual countermeasures, the firms and genba facing a major disaster have to plan and implement an effective course of action, or recovery project, both at the level of each product/part item and in terms of the total product/process mix of each firm. As already discussed in this book, at the level of each product/part item, there are two basic types of recovery projects: *recovery on the spot* and *substitutive production*.

In terms of the total product/process mix of each firm in the supply chain, we argue that these two anti-disaster measures should not be treated separately but regarded as mutually integrated parts of the overall anti-disaster capabilities of firms and industries. In other words, the firms and sites in each industry's supply chain need to build capabilities for both rapid recovery and rapid substitution. Actors need to be flexibly combine or switch between these two approaches, since post-disaster situations are unique each time and change rapidly and unpredictably.

One combined strategy at the firm level may be called *virtual dualization*, and it is the combination of quick recovery of the damaged site itself and quick substitution by transferring design information to an intact production line. This means that a line that is potentially flexible is actually made flexible, so that the two lines are treated "virtually" as dual tooling lines, although they may make different products in normal times.

Let us now discuss quick recovery and quick substitution. Subsequently, we will illustrate virtual dualization later in the chapter.

3.2. Quick Recovery on the Spot

Principles and Trust

We will briefly summarize here this book's discussion of the principles, practices and capabilities needed for quick on-the-spot recovery of damaged production equipment and lines.

The companies that play a leadership role in the supply chain in question (e.g., "the leading firms," which in many cases will are the downstream product companies) should propose policies and principles that the other firms and sites in the supply chain can accept and share. Relationships rooted in mutual trust will provide a strong foundation for such policies and principles. For example, based on Toyota's principles, which the company has repeatedly declared, priority is given to the recovery of its damaged suppliers' production lines over substitutive production and that, if substitution is unavoidable, it chooses other lines of the disrupted supplier over other suppliers (Chapter 8). Such a declaration made in normal times will motivate upstream suppliers to commit themselves to this supply chain and improve their competitive and anti-disaster capabilities simultaneously.

Here, again, supply chain robustness and competitiveness are treated in an integrated manner. Substitutive production may eventually be chosen as a temporary or permanent measure but, if the decision is taken only after the supply chain leader has spared no effort to help in the recovery of the damaged line, this hard choice is likely to be found acceptable by members of the supply chain and the trust relationship among them can be expected to continue.

One may argue that Toyota's readiness to help damaged sites may create a moral hazard on the side of the suppliers, but the intervention by Toyota in the recovery process is also an opportunity to evaluate a supplier's competitive capabilities. In fact, Toyota uses the recovery process as an opportunity to improve the damaged suppliers' competitive capabilities as well.

Supply Chain Triage

When a major disaster occurs, each leading firm engaged in the recovery assistance activities should quickly set up a temporary organization that will serve as a "supply chain recovery assistance center" within the firm's department or division that has the greatest responsibility for supply chain management (e.g., production control, purchasing, logistics, etc.) and appoint a senior manager as head of the organization. First, decisions must be made about which sites need rescue and recovery assistance, since the resources for this activity are usually limited. This first step, which we may call "supply chain triage", is particularly important when a disaster affects many suppliers, as in the case of the 2011 Tohoku Earthquake. By using all possible sources of information, the leading firms in supply chain have to promptly classify potentially affected suppliers into different categories, such as: (1) "Intact" (little or no damage and therefore there is no need offer help); (2) "Substitute" (there is no hope for quick recovery due to complete destruction); (3) "Recover" (quick recovery within the target lead times is highly likely, if recovery assistance is provided by the leading firm or firms); (4) "Both" (with assistance, quick recovery may be possible, but as it is not a certainty, substitute production should also be pursued).

Assistance to damaged sites from the leading firms will be needed in cases (2), (3) and (4). Efforts for on-the-spot recovery need to be concentrated on those suppliers classified as (3) "Recover" and (4) "Both". On the other hand, assistance for substitutive production will be needed in cases (2) "Substitute" and (4) "Both". Hence, based on the initial triage, the leading firms will need to make quick and reasonably accurate plans to allocate resources among the suppliers and activities and continually update these plans.

Recovery on the spot is usually preferable to substitution because it improves motivation at damaged sites, while also avoiding the possibility of capacity shortages at substitutive production lines. However, lead times for on-the-spot recovery tend to be more unpredictable, since the real extent of the damage may only be fully revealed as the recovery work goes on.

If the initial triage classification is (4) "Both", the leading firms and the suppliers in question should start preparations for both on-the-spot recovery and substitution, while continually checking the progress made, particularly of the former. If they later become confident that sufficiently quick on-the-spot recovery can be achieved, then they may stop preparations for substitutive production (e.g., reclassify from (4) "Both" to (3) "Recover"), provided of course that substitutive production has not already begun. Alternatively, they may opt for dual production at both the recovered line(s) and substitutive line(s), at least temporarily, if they judge it best for their future preparedness and flexibility. In any case, the leading firms should give priority to the damaged lines classified as (3) "Recover" or (4) "Both," while also continually checking the overall situation and changing categories whenever necessary.

Recovery Resource Planning

Once the leading firms decide which damaged sites need help, they should assemble a small "advance team" for each of them, choose feasible means of transportation and reach the genba as soon as possible.

The advance teams may include different members, depending on the types of affected processes (e.g., machining, assembly, chemical) as well as the type and severity of the damage (e.g., collapsed building, fallen equipment, fire, flooding). However, the typical candidates are managers and engineers in charge of supply chain management (e.g., production control, purchasing, and logistics), plant building engineering, and communication facilities. The advance team should also include someone who is capable of quick and accurate judgments/decisions/actions who can serve as the recovery project planner. The skills that such leaders will need to be effective should be developed in normal times primarily through on-the-job training in intensive problem solving (e.g., kaizen activities), which may be supplemented by~~/or~~ formal training courses. Those who could potentially become such leaders and members of the advance team will obviously work in different departments, so the leading firm should prepare a list of candidates and keep it constantly updated.

When they reach a damaged site, the members of the advance team should see the plant's managers to gather information on employee safety and physical damage, inspect the damaged site, and visit the surrounding community to find out about their critical needs. The team should then make an appropriate recovery plan to be used by the main recovery assistance team that will take over the activities from the advance team. The recovery plan should include the following: (i) the size of the main team and required types of expertise; (ii) recovery actions needed and their sequence; (iii) types and quantities of tools, equipment, and materials needed for the recovery; (iv) accommodation and means of transportation available to the main team; (v) orders for the initial provision of food, water, and other rescue materials for the surrounding community, employees at the damaged site, and the main team, along with a replenishment schedule; (vi) organizational design of a joint recovery project team where recovery assistance team(s) will work with the damaged site's own workers and managers, including designation of the leaders, creation of specialized units, reporting/instruction/communication channels, timing of information-sharing meetings, and other necessary tasks.

The elements of the recovery plan should be constantly reevaluated as the situation at the damaged genba evolves, but quick and effective initial planning will dramatically enhance the speed and effectiveness of the subsequent recovery processes, as in the case of *front-loading problem solving* in normal engineering (Thomke and Fujimoto 2000). We may call such early planning: Rescue-recovery Requirement-resource Planning or "RRP".

It is worth noting that, unlike MRP (Material Requirement Planning) or MRP II (Manufacturing Resource Planning), RRP cannot fully rely on computers. Ultimately, the "computing power" of the brains of the leader and members of an advance team will be indispensable as they walk around the damaged genba, estimate the type and severity of the damage, identify the recovery activities and their sequence, and quickly calculate the approximate quantity of required resources on the spot. This is exactly what Mr. A did at the genba struck by the 1991 Flooding and the 1995 Earthquake (see Chapter 8).

Building Trust and Encouraging Each Other

There is another intangible resource that is indispensable for the recovery of damaged sites, namely, that there exists a shared sense of commitment and trust among the surrounding communities, affected suppliers, and the recovery assistance teams sent from the supply chain's leading companies.

Without such teamwork—or a "one for all, all for one" spirit—at the damaged genba, quick recovery is difficult even with high individual skill levels and an abundant supply of physical resources. So, one of the important tasks of both the advance and main recovery assistance teams is to promote relationships based on trust and provide mutual encouragement to all those involved in the recovery effort, including simply cheering each other up.

At the sites that have experienced severe human and physical damage, it is quite natural for workers and people in the community as a whole to be distressed and become defensive and skeptical. In such a situation, the recovery teams coming from the outside may have to take a leadership role in promoting a positive atmosphere. However, such efforts should not be done forcefully but rather through persuasion, for example, by showing a constructive spirit through one's actions.

In disaster scenarios, suppliers often fear that a customer company may rush to a damaged site only to try to move tools, equipment, and inventory to another location, in order to start permanent substitutive production somewhere else, thereby abandoning the affected genba. However, for those leading firms that follow the aforementioned policy of "recovery on-the-spot first", the advance teams should not only clearly state this policy verbally, but also show it by immediately initiating practical actions that demonstrate a commitment to on-the-spot recovery.

Support actions of the advance and main recovery teams should also be directed toward the surrounding local communities. We should never forget the reality that any manufacturing site, damaged or intact, belongs not only to the parent company but also to the community living around it. The surrounding community relies on the employment and purchasing power provided by the site, whereas the site itself needs the legitimacy provided by the community. Therefore, if a recovery assistance team comes in and displays a "production first" or "my company first" attitude, this will diminish the legitimacy not only of the leading firm but also of the damaged site in the eyes of the surrounding community. This is one of the reasons why initial assistance should be provided to the surrounding communities as well, particularly in cases where the local government's relief operations are slow and insufficient.

The advance team's mission to provide the damage site and surrounding community with the intangible asset called trust will pave the way for smooth collaboration between the main assistance team and people from the damaged supplier. Thus, for example, we see that Toyota has been pursuing a very consistent principle of "human rescue first, community second, production third" and "recovery of Toyota's production lines last" in times of major supply chain disruptions, and it is self-evident that a selfish "recovery first" or "me first" mentality will not work in such extreme situations.

Quick Team Assembly

After the preparatory work carried out by the advance team, it is the main recovery assistance team's turn. Based on the initial RRP provided by the former, the supply chain's leading firm(s) should quickly assemble and prepare the main recovery assistance team(s), using the lists of capable people compiled from previous recovery experiences and those with particularly high skill sets in production improvement (kaizen). Such lists need to be up-to-date, and therefore must be constantly updated. Those who are selected as potential rescue team members should, in turn, keep this possibility in mind and make sure that they maintain the required skills and that they are mentally prepared to instantly swing into action.

Moreover, a rule needs to be instituted during normal times and followed by section managers and those above them that, if the need arises, these potential candidates must be immediately released from their present duties in order to travel to the damaged site without delay. In other words, leading firms should make sure that all employees understand that a mentality that says "my section first" is never allowed in an emergency situation. This same approach is also needed when special orders come from the advance team, such as asking section A to send its special expert B to the team, even if this person was not on the pre-specified list.

Lastly, potential team members should train in a variety of skills, including traditional techniques that may have been abandoned but are still helpful when modern equipment is not usable or accessible due to severe destruction, energy shortages, or power line stoppage.

Quick Implementation

Once the main recovery assistance team arrives at the damaged site, it must move very quickly and accurately. Past experiences show that it takes an ineffective team much longer than an effective one to complete the same recovery task.

Busses and trucks, owned or chartered by the leading firm, are often used to transport the team, recovery materials and rescue provisions to the damaged site whenever feasible. Travelling to the site together allows the main recovery assistance team to use all the initial information provided by the advance team and begin creating a detailed recovery plan on its way to the genba (front-loading problem solving). With such preparations, the team can start working immediately upon its arrival. Potential bottlenecks and critical paths should be identified before arrival and the sequence and priorities of the recovery activities should be discussed and shared among the team members. However, the team should not forget that their first task is to take care of the employees, their families and the surrounding communities by providing rescue provisions and helping them whenever possible.

After the team's arrival, the abovementioned work plan should be discussed with the employees of the damaged site and modified accordingly, as there is often additional information that the assistance team did not know until they arrived at the site. Since it is natural for people at the damaged genba to be unsettled and confused, the recovery team in actuality often has to take a leading role, but this should be done through suggestions and assistance and not by ordering or taking imposing actions. The main recovery assistance team should coordinate closely with employees of the damaged site by quickly forming a joint recovery project team, with a senior manager of the damaged site appointed as its head. All the elements of the joint team's structure have to be agreed between the two firms in advance, as mentioned above.

The recovery work should be conducted in a timely and accurate manner through collaboration between the supplier's team and the recovery assistance team. If the plan is to perform various tasks simultaneously, then specialists should be deployed to the right places and start working at once, but flexible redeployment and coordination is needed, as anything can happen in such situations.

Conversely, if the recovery project requires sequential processes (e.g., fixing pipes first and electrical equipment next), the team will need to have multi-skilled specialists who can perform not only their specialized tasks but can also do other things reasonably well (e.g., a piping specialist who can also do simple electrical wiring), while also helping one another in each sequential task. An ineffective approach to recovery, which should be avoided, is a combination of sequential activities and a complete lack of multi-skilled personnel because, in such cases if the sequence is "task A→task B", then the B specialists will be idle while task A is going on, and vice versa.

Whether or not people from the damaged site are able to assume real leadership roles, the leading company's main recovery assistance team will need to exercise effective, yet non-domineering, leadership at one level or another, since crisis management is a highly orchestrated job marked by constant changes and uncertainty. However, outside individuals should exercise such leadership not by abusing their authority or power but by persuasion, suggestion, assistance, logic, and sympathy. The damaged site is, after all, not owned by the people providing support from the outside.

This pattern of effective implementation of joint recovery tasks—namely job simultaneity, multi-skilling, supplier involvement and strong leadership—is strikingly similar to that of competitive product development projects for coordination-intensive products, such as automobiles (Clark and Fujimoto 1991). In a sense, this is a natural consequence of the fact that developing a high-performance car and rebuilding a damaged manufacturing site both require a highly coordinated project team of multi-skilled specialists.

3.3. Quick Substitutive Production

Substitution with Design Information Transfer

As mentioned earlier in this book, quick on-the-spot recovery and substitutive production are two basic types of recovery projects that leading firms in the supply chain may initiate for each product/part item affected by a supply chain disruption. Let us now discuss the course of action and capabilities necessary for quick and effective substitutive production. We will focus on the concept of *design information transfer*.

If a supplier has two product lines making a product of identical design information, then there is no need to transfer the design information from the damaged line to the intact one. In cases where there is such dual tooling, or what could be called "actual dualization" of production lines, the supplier will simply increase the production volumes on the intact line (provided the line is not already running at its absolute maximum capacity) to make up for the production lost on the damaged one, while also rerouting the supply chain accordingly. This measure can be carried out by using a firm's ordinary manufacturing capabilities and production systems.

We will therefore focus on the case in which a firm needs to develop additional capabilities in response to a major disaster—substitutive production with transfer of critical design information from a damaged line to an intact line that makes similar but different products. Possibly with the help of the leading firms, the supplier in question will have to carry out the following activities: detaching information or duplicating information, transferring information and re-embedding information.

Detaching Information

First, the affected manufacturing site has to "detach" the product-specific design information from the damaged line, so that it can transfer it to the intact line. How to do this depends upon the "portability" of the critical design information in question. Suppose that such critical design information was intact in the damaged production line. If it is a line of stamping machines, dies can be detached relatively easily. If it is an ordinary NC machine tool or a robot, the motion control programs and cutting tools can be easily detached from the machine as well. Product-specific recipes at a chemical plant may be relatively portable too, as long as said plant is fully standardized and digitized. Yet, if the recipe is embedded in tacit knowledge and/or contained in complicated documents about operating procedures, then the control room operators may have to move as well, at least temporarily.

On the other hand, if it is a line of special purpose machine tools or welding jigs dedicated to a single product (e.g., a high-volume automobile engine block machining line), then the critical design information is embedded in the entire hardware of the equipment, so the supplier may have to detach the whole piece of equipment from the floor or the bed plate by pulling out the anchors. The chances that a large piece of equipment might be wholly intact when the production lines are destroyed will be much lower than in the above cases of tools, dies, and programs. In addition, as the critical design information is embedded in said large and bulky equipment, technicians specializing in installing, maintaining, and demolishing heavy machines may have to be called in to complete the detaching work.

Duplicating Information

If the critical design information specific to the product in question is damaged together with the production line, then the supplier will have to reproduce it by moving upstream along the engineering chain to obtain the original product/process design information. Retrieving three-dimensional CAD-CAM product information and reproducing physical dies of identical shape is a typical example of design information duplication.

The capability required for this task is nothing but the capability a firm must have for quick product-process development (Clark and Fujimoto 1991). This is particularly true when the destroyed critical design information is not portable, so that the whole production line has to be reproduced from scratch.

Duplication of product-specific design information after a disaster, rather than investing in two identical lines (dual tooling) before a disaster, will be cost saving if having dual tooling in normal times would excessively reduce capacity utilization ratios and increase fixed cost burdens, and if the supplier is capable of reproducing the tools and dies quickly. In other words, keeping duplicable design information in normal times, instead of having physically duplicated tools and equipment, is a competitive way to prepare for disasters if the firm has quick product-process development capabilities.

Transferring Information

The work of moving the critical design information from the damaged line to the intact one will differ depending upon the nature of the medium on which the design information is embedded. If what is transferred is the software embedded in digital electronic media, this information transfer will be nothing but telecommunication that is completed instantly. If it is physical dies/tools/equipment, then it will involve transportation of heavy machinery.

The substitutive production line to which the design information is transferred may be a line in another plant of the same supplier, a line of its subcontractors or customers, or even a line in competitor's plant, but the social or human implications of substitution should be carefully considered in this case. For instance, if the whole production line moves from the disaster-affected site to another location, particularly if it moves to a plant of a customer or competitor, people may interpret this as a permanent loss of that line, unless there are clear plans to move it back to the original location once the original site is restored.

Thus, not only technical/economic aspects but also social/ psychological perspectives should be taken into account by both suppliers and leading firms when transferring design information.

Re-Embedding Information

Once the critical design information, whatever its form, arrives at the substitutive production line, the transferred deign information has to be re-embedded into the substitutive production line.

Since the two production lines are not identical, various types of adjustments will be necessary, such as rewriting of NC software, realignment of dies and machines, modification of recipes to fit the new plant, retraining of operators, and so on. In the case of highly functional chemical plants, for example, detaching recipes from the damaged plant may not be a major problem, but quickly and accurately re-embedding them into the substitutive plant may be a challenging task.

"Evacuation Drills" of Design Information

As a whole, the quick start of substitutive production through detaching or duplicating, transferring, and re-embedding is a complicated task. So, if the supplier in question already has two production lines that make similar products, it should conduct "evacuation drills" of critical design information between the two lines to increase the chances of keeping its orders even if one of its sites is destroyed and quick on-the-spot recovery is difficult. During these drills, the supplier, possibly with the assistance of the leading firm, will need to try different ways of successfully achieving the substitutive production indicated above, such as by quickly detaching, transporting and readjusting dies, quickly reproducing and readjusting new dies, and so on. Such drills need to be conducted in both directions; that is, both plant must be made capable of quickly substituting the production of the other.

Suppose, for example, that a supplier's target recovery lead time for an item is two weeks. If the design information evacuation drills make the supplier capable of starting substitutive production inside the company and within the set time, then it will likely be able to keep the job even if a disaster causes damage to a production line that is so severe that the line's quick recovery seems impossible.

Evacuation drills of critical design information are useful not only to suppliers in general but also to each specific plant, in order to increase the chances that employees from damaged sites will be able to move to the substitutive lines and keep their jobs and that those jobs will come back when the recovery of the damaged genba is complete.

3.4. Supply Chain Virtual Dualization

What is Virtual Dualization?

We have so far discussed two main ways of responding to supply chain disruptions for each individual product/part item, e.g., *quick recovery on the spot* and *quick substitutive production*. The leading firms in a supply chain, however, may want to combine these two methods rather than only use them independently, so that recovery and substitution may be integrated into a more comprehensive process for achieving total supply chain robustness. We will examine one such combined method, which has been observed and discussed various times in the present book: *virtual dualization* or virtual-dual sourcing.

Suppose that a supplier has at least two "similar" production sites in different regions and many part items to be produced. Here "similar" means that the products and processes of the two sites are similar enough to make quick substitution between them possible within the target lead times. Suppose also that the quantities of demand for each item produced at the two sites are rather small, so it is impossible to achieve minimum efficient scales if each is produced on both lines. Therefore, in this case, the competitive product-process configuration for this supplier is to produce each item at only one production site.

This means that, if a major disaster severely damages one of these sites, the supplier has to opt for either quick on-the-spot recovery or quick substitution or both, depending on the damage suffered. However, if the firm has sufficient capabilities to keep within target lead times and costs regardless of the severity of the damage, by using quick recovery and quick substitution in flexible ways, we may say that in effect this supplier can respond to any major disasters as if it actually had two identical production lines. This is why we call the two lines "virtual dual".

From the standpoint of the producers of the final product (e.g., car manufacturers), this virtual-dual system and the capabilities to be able to execute virtual dualization are also preferable, as they will increase the probability of achieving the target lead times for the total supply chain, regardless of the type and severity of future disasters. Furthermore, the virtual-dual solution will be more cost effective than double tooling (actual dualization), which causes fixed cost penalties due to producing below the minimum efficient scale for each item.

For a small local supplier that has only one production site, pursuing virtual dualization on its own does not represent a viable option, so such small suppliers may have no choice but to fortify their production site and build up capabilities for rapid on-the-spot recovery. However, such small firms may choose to team up with other small firms with "similar" products and processes so that, in times of emergency, virtual dualization may be jointly carried out by a group of small suppliers.

In industries with a large variety of parts that are specific to a customer's product, such as automobiles, it is impossible for all the suppliers in the total supply chain to have actual dual/multiple lines (or dual/multiple tooling) that are also cost competitive. If, on the other hand, the leading firms in a supply chain and suppliers work together to improve capabilities for both rapid on-the-spot recovery and rapid substitution and combine them flexibly to create a virtual-dual system, such a supply chain will be able to achieve a reasonably high level of robustness without sacrificing cost competitiveness.

Actual and Virtual Dualization

It is important to stress that virtual dualization does not exclude actual physical dualization, or having multiple lines that produce products of identical design information. As discussed earlier in this book, adopting actual dualization for certain items does not represent a problem, and may even be advisable, as long as it does not sacrifice competitiveness, because the cost to attain supply chain recovery is usually lower if another identical line exists.

Stated more specifically, if a particular item can be produced at all the substitutable production lines in volumes at or above the minimum efficient scale per period and lot size, with all fixed equipment costs (including set-up-change costs and transportation costs) taken into account, then having two or more production lines, whether dedicated or mixed model lines, is preferable because, in an emergency, target lead times are likely to be shorter and the costs for substitution lower than if other countermeasures are adopted, like design information transfer.

From the standpoint of the overall product-process combination of a typical firm in an automotive supply chain, however, it is unlikely that there will be very many product/part items that can reach the production volume levels needed to justify actual dual/multiple production from a competitive standpoint. For example, suppose that a second-tier supplier of items used in brake parts has two plants of similar sizes (plant 1 and plant 2), produces one hundred different items for multiple customers, and only twenty items achieve their minimum efficient scales when produced at both plants. The most competitive product-process configuration for this company would be actual dualization (dual tooling) for the twenty top items and single factory production for the rest, forty items at each plant, for instance. If a major disaster hits factory 1, while dealing with on-the-spot recovery, the supplier will simultaneously carry out substitutive production expansion at factory 2 for the twenty top items and design information transfer to factory 2 for the other forty items. This supplier will still need to have sufficient capabilities for virtual dualization even though some of its products can rely on actual dualization.

To sum up, we argue that, in the multi-product production that is common today, actual dualization will be possible for some high-volume items, but it would make the most sense to adopt such dual tooling as part of a larger virtual-dual production system for supply chain robustness.

Leading firms in a supply chain and suppliers should both make continuous efforts to increase the number of actual dual production items, by reducing fixed costs and minimum efficient scales through process innovations, by reducing set-up-change costs, and through lowering efficient lot sizes through kaizen, by redesigning the items as common parts across models and countries to increase volumes, and so on. And yet even so, it will still likely be difficult for all the items that they produce to be made using actual dualization without sacrificing competitiveness. Thus, firms need to build capabilities for virtual dualization even when actual dualization is possible for some of their product lines.

Principles and Logic of Virtual Dualization

The basic rules and course of action for virtual dualization can be illustrated as follows. Again, the goal is to try and achieve supply chain competitiveness and robustness at the same time.

Choose a competitive product-process configuration for normal competitive environments. Each production line can be either flexible (mixed model) or specific (dedicated). Each product item can come from either single line production or multiple line (e.g., actual dualization) production.

When a disaster/disruption happens, choose appropriate countermeasures. If the ultimate goal of the supplier is to recover the damaged plant and return to the original configuration, which is expected to still be competitive, then the firm can choose between "recovery only" and "both recovery and substitution". Choose "recovery only" whenever the estimated recovery lead time (R) is shorter than the target lead time (T) or substitution lead time (S). Substitution is not needed in this case. Choose "both recovery and substitution", meaning that substitutive production is used temporarily until recovery, when the estimated substitution lead time (S) is shorter than the recovery lead time (R). The firm may use its discretion when S≦R≦T.[5] In any case, continue recovery activities for the damaged line in parallel with starting substitutive production. It should be underlined that free-of-charge assistance by leading firms in the supply chain is expected in all cases, so recovery cost is not considered here for the sake of simplicity.

When substitutive production is chosen, expand production and change shipping routes in cases where actual dual production had been adopted before the disaster. Otherwise, detach or duplicate, transfer, and re-embed design information from damaged lines to "similar" back-up lines in the form of tools, programs, skills, etc.

When production can be resumed through either "recovery on the spot" or "(temporary) substitutive production", start whichever occurs earlier.

When the damaged line is recovered, revert to normal production in the original product-process configuration. If recovery proves to be difficult and time-consuming, look for a new configuration. Configurations may also be changed in the long run, but such changes should be made based primarily on considerations of competitiveness, not fear of future disasters.

Figure 2 is a simple model of the virtual-dual rules mentioned above, with 2 production lines and 2 products, assuming that the firm in question was producing products A and B on production lines 1 and 2 in a competitive way prior to the disaster. The three possible product-process configurations are as follows:

[5] Using the expressions here, choose "recovery only" if R≦T or R≦S. Chose "substitution only" if S≦R. The case where recovery is achieved in time but substitution starts even earlier (S≦R≦T) is an indeterminate case. A firm may choose between "recovery only" and "both recovery and substitution." The latter means temporary substitution until recovery is complete.

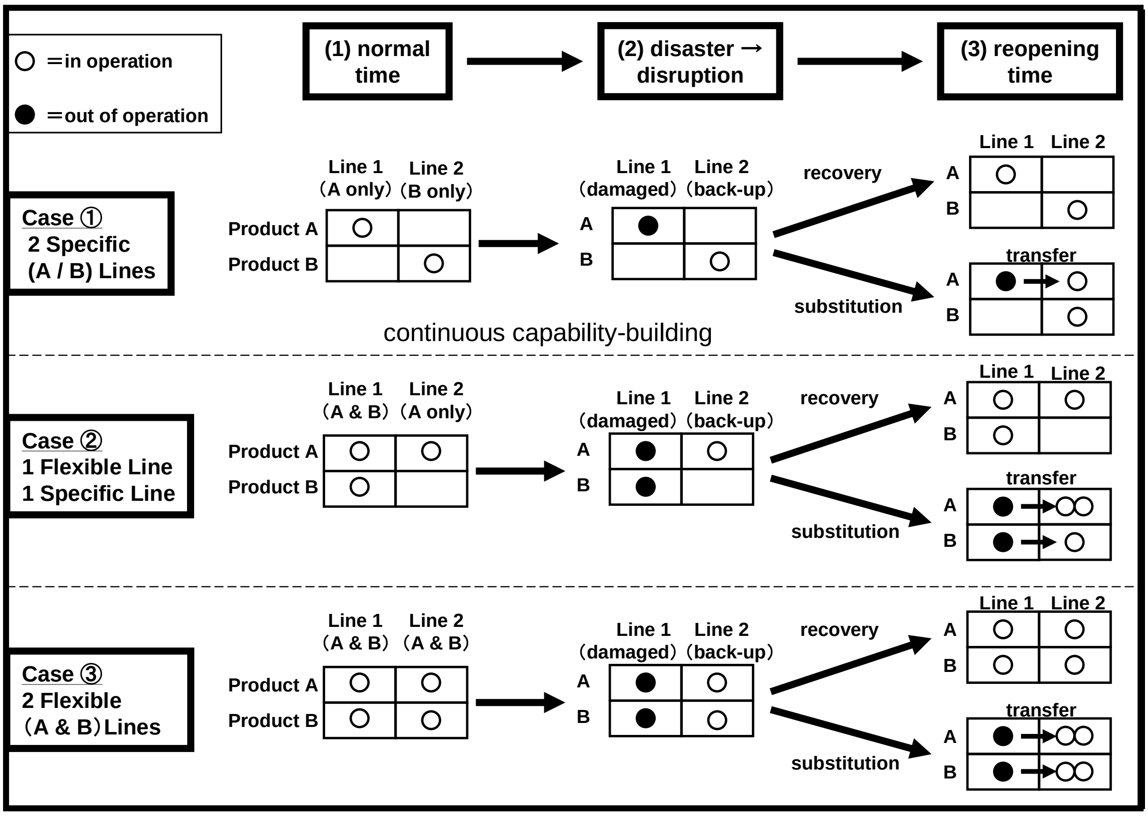

Figure 2. A model of virtual-dual sourcing (2 product, 2 lines).

Case (1): Two specific lines (line 1 for product A, line 2 for product B), no actual dualization.
Case (2): One specific line and one flexible line (1 for A and B, 2 for A), actual dualization for A.
Case (3): Two flexible lines (1 for A and B, 2 for A and B), actual dualization for both A and B.

Product A in Case (2) and products A and B in Case (3) are cases of actual dualization, which the supplier recognized as competitive (e.g., achieving minimum efficient scales at both lines, 1 and 2) in normal times.

To summarize, virtual dualization is a capability-oriented countermeasure against major disasters that aims at both supply chain competitiveness and robustness through collaboration between leading firms in a supply chain and suppliers.

First, the firms in the supply chain jointly build competitive capabilities for flexible and flow-oriented manufacturing. Leading firms in a supply chain often support the capability building of suppliers through kaizen (improvement of flows).

Second, firms choose product-process configurations (e.g., what is produced where) by taking into account the capabilities and competitiveness of each site and product. Dual tooling, or actual dualization of the lines for each product/part, should be chosen only when it is compatible with the criteria for competitiveness.

Third, the leading firms in the supply chain and critical suppliers jointly build anti-disaster capabilities in terms of both (i) quick recovery of the damaged line and (ii) quick transfer of design information from the damaged line to the intact lines. The leading firms at the core of the supply chain should take the initiative here, because they usually have much more experience in supply chain disruptions. These anti-disaster capabilities share many characteristics with flow-oriented competitive capabilities, as they are both related to management of design information flows.

Fourth, if a disaster destroys the production sites of suppliers, leading firms in the supply chain quickly help them recover the production lines that have been damaged. Substitutive production, with or without design information transfer, may additionally be adopted, but it is mostly regarded as a temporary measure until damaged lines can reopen.

Fifth, assuming that the original configuration was already competitive prior to the disaster, the general consensus within the supply chain should be that the production jobs will eventually return to the damaged sites once they have been recovered. This “recovery first” principle is preferable not only from the standpoint of supply chain competitiveness but also to build relationships that feature trust between firms producing final products, suppliers and communities, which in turn becomes the source of long-term competitiveness.

Virtual dualization is a set of principles designed to contribute to achieving supply chain competitiveness and robustness at the same time, particularly in the case of complex integral products that contain many product-specific parts, whose design and production require intense coordination between leading firms and suppliers. Different reasoning may be better suited to different types of industries, but the key task for all industries is to establish flexible but internally consistent principles before the next disaster strikes, so as to minimize confusion and speed up recovery.

3.5. Preparing for Future Disasters

The present book explored a capability-building approach to supply chain robustness against major disasters. Rather than focusing only on business continuation and anti-disaster countermeasures, we tried to propose a more balanced view between supply chain competitiveness and robustness. We selected case studies of industrial sites, or genba, to extract the main principles and logic behind their actual activities and practices before and after major disasters. In addition, we looked not only at the managerial/operational side but also the organizational/social aspects of recovering from destructive disasters.

We chose manufacturing firms in Japan in the post-Cold War period as our main case studies. By doing so, certain biases toward Japanese idiosyncrasies may be inevitable. Yet, we believe that an in-depth analysis of firms operating in a country affected by frequent natural disasters and striving to survive in a period of unusually intense global competition may offer various insights to international readers who are interested in the critically important topic of minimizing the loss of life and damage to industrial sites caused by disasters, while not sacrificing competitiveness.

This book emphasized the importance of collaboration between people and firms, coordinative practices, trust, communication, information sharing, sympathy, leadership, guiding principles, disciplines, priorities, critical judgments/decisions/actions, deep knowledge of genba, human resource development, and so on.

However, there may be other approaches to this topic. For example, one can argue that, for open architecture products where most parts can be purchased and sold through arm’s length transactions in the market, the massive assistance that some Japanese leading firms, like Toyota, provide to their damaged suppliers whenever a disaster strikes is probably unthinkable. The same logic will apply to small subcontractors making highly substitutable parts, which may have to economically survive by themselves without assistance from supply chain leaders.

However, in these industries too, the downstream, final product firms may find that there are quite a few critical parts on which they depend heavily on a single supplier, and this dependence may be revealed only after the destructive effects of a disaster have occurred. Besides, such critical parts suppliers of open architecture products, although they tend to be more independent, may not possess sufficient resources for quick production recovery when a major disaster strikes, so that they may still need significant help from the supply chain leading firms as customers. This means that the supply chain leaders need to be well prepared to make effective recovery assistance not only for their interdependent suppliers of product-specific parts but also for those of critical standard parts.

Others may argue that the analysis of business continuation should be more economic than operational, and we agree that this volume should be read together with other complementary books on business continuity planning with heavier economic and business orientations. However, our observation in writing this book was that there had previously been relatively few works focusing on the operational and behavioral side of business continuation activities based on empirical research—and our aim was to try and fill this gap as best we could.

Thus, despite some limitations concerning generalizability, we believe that this book can contribute to the existing body of knowledge in the areas of supply chain management and business continuity management, by providing new perspectives such as continuous capability-building and an integrated approach to achieving both supply chain competitiveness and robustness.

In retrospect, one of the initial motivations of the authors in writing this book was the shock we felt when faced with the 2011 Great East Japan Earthquake, as well as our observations of the struggling communities and plants in the immediate aftermath of the disaster. We also acknowledge that following the earthquake, devastating tsunamis, and nuclear disaster, enormous amounts of rescue provisions, practical help, and donations came to Japan from all over the world. In a sense, this book is meant to be a small token of gratitude to the world outside of Japan for that generosity, in the form of additional knowledge on how industries and firms may fight against future disasters.

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