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Key Concepts for Improving Supply Chain Robustness

Takahiro Fujimoto

Graduate School of Economics,

University of Tokyo, Tokyo, Japan

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東京大学ものづくり経営研究センター
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KEY CONCEPTS FOR IMPROVING SUPPLY CHAIN ROBUSTNESS[1]

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

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Abstract

This chapter describes the *design information flow* view of manufacturing that serves as the main framework undergirding the entire book. This approach provides a means to identify the potential weak links in a supply chain, namely wherever there is information dependence, invisibility, non-substitutability, and non-portability. Materials and parts provided by a supplier that meet these criteria are vulnerable to becoming bottlenecks in the supply chain following a disaster, and therefore they should be managed to minimize the risk of disruption. In addition to outlining the conventional means to deal with such vulnerable links, the chapter describes an approach called “virtual dualization” as a novel way for firms to build their capabilities so that they may overcome the tradeoff between supply-chain robustness and competitiveness that is typically seen when only the conventional countermeasures are employed.

Keywords

Engineering chain, Flows of value added, Value-carrying design information, Medium, Purchasing, Market performance, Kaizen, Flow stoppage, Flow continuation, Re-embed, Aisin Seiki fire, Diamond-shaped structure, Virtual dual, Bill of materials, Supplier-process specific, Integral architecture, Product-specific parts, Black-box parts, Product-specific, Die, Chuetsu offshore earthquake, NC programs, Non-portability, Supply chain diagnosis, Invisibility, Non-substitutability, Anti-disaster drills, Post-disaster measures, Preventative measures, Precautionary measures, Back-up production, Muda, Lewis turning point, Global capability-building competition, Productive performance, Disaster-first mentality, Food reserves, Water, Emergency reserves, Target recovery lead time, Supply chain weaknesses, Standard parts, Over-design, Value engineering, Common parts, Comparative advantage, Competitiveness, Product development, Dual tooling, Dual sourcing, Dualization, Minimum efficient scale, Utilization ratios, Moving factories, Hollowing out, Relocation, Disperse, Productive resources

1. ANALYZING SUPPLY CHAIN ROBUSTNESS AND WEAKNESS

1.1. A Design Information View of Manufacturing

As discussed in Chapter 1, the purpose of this book is to explore the ways in which, in the age of global competition, industries and firms can effectively deal with major disasters, such as earthquakes, and make their supply chains competitive against rivals at the same time. Our surveys in Chapter 2 indicate that academic empirical and theoretical research on the topic, in the areas of social sciences, economics and business, has not yet been sufficient to make adequate preparations for the future. Against this background, the rest of this volume will analyze cases of good practices implemented by firms and industrial sites (*genba*), focusing particularly on some disasters occurred in Japan in the post-Cold-War era, when the trade-off between competitiveness and robustness was at its most severe (Fujimoto and Park 2014).

In order to carry out this case-based empirical analysis, we need certain frameworks and concepts to identify the weak links and vulnerable points of a given supply chain, so that we can select the cases of firms and genba struggling to alleviate such weaknesses.

For this purpose, this chapter will first describe the supply chain from the aforementioned standpoint of the *design information view of manufacturing* (*monozukuri* in Japanese), which enables us to simultaneously analyze the so-called engineering chains and supply chains, e.g., the product design and production process aspects of manufacturing in a broad sense (Clark and Fujimoto 1991, Fujimoto 1999, 2007). So, to begin with, let us reinterpret the concept of supply chain through the design information view of manufacturing.

As briefly mentioned in Chapter 1, our broadly-defined concept of manufacturing, or monozukuri, refers to all the activities of firms and genba aimed at creating effective, efficient and timely *flows* of value added to the customers in the market. We also argue that the value added of products or services resides in *design*, or information and knowledge about the relations between an artifact's functions and structures (Simon 1969, Suh 1990). We can therefore adopt a broad definition of manufacturing seen as creating and maintaining effective flows of value-carrying design information to the customers or, more simply, "*creating good flows of good design information to customers.*" This is the basic concept of monozukuri as it is taught in Japan and the theoretical interpretation of the Toyota Production System as well (Heller and Fujimoto, 2017).

Within this framework, both products and productive resources (Penrose 1959)—such as production equipment, tools, dies, jigs, numerical control software and hardware, work-in-process, incoming parts and materials, as well as human operators as workforce—can be regarded as a combination of design information and its medium (in the form of material or energy). This may be seen as a modern interpretation of Aristotle's idea that an individual object is a combination of form and material.

It follows from this view of manufacturing that the flows of materials, both inside the factories and along the supply chains, are not just material flows but "design-information-and-material" flows. For instance, if a half-finished component moves from one machining station to another inside a factory, we regard this as a flow of value-carrying design information that is embedded in the material. In the same manner, we reinterpret (i) *production* as transferring design information from the process to the material as medium; (ii) *product development* as creating design information and its transfer to productive resources, such as design drawings and stamping dies; (iii) *sales* as transmission of complete design information (e.g., the product) to the customers, and (iv) *purchasing* and *supply chain management* as maintaining the total flow of value-carrying design information (or value stream) embedded in the media (materials) between the suppliers and firm sites and the customers.

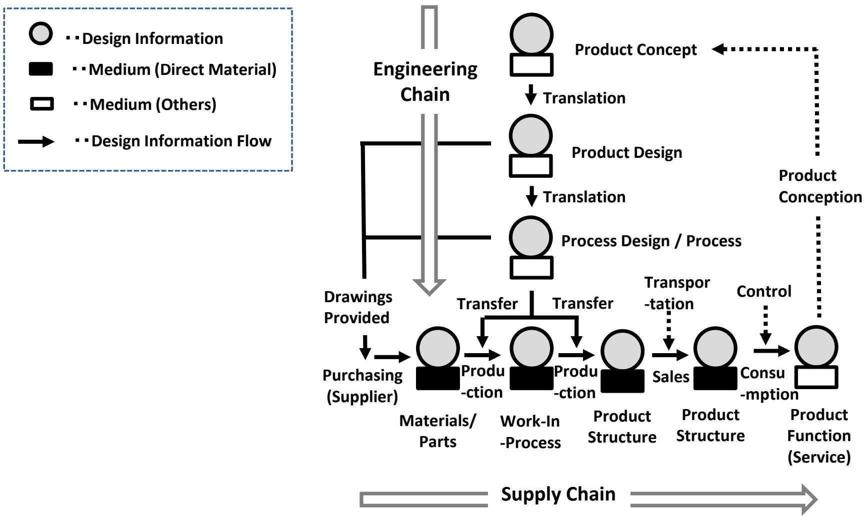

Figure 1. Circulation of Design Information between Firms and Customers –
A Broader View of Integration Supply and Engineering Chains.

To sum up, our broadly defined concept of manufacturing, or monozukuri, covers not only production in a traditional sense but also product-process development, sales-marketing, purchasing, as well as supply chain management in relation to a given product or service, as long as these activities manage and control its flow of design information to the customers.

This design information view is presented visually in Figure 1. In this diagram, the horizontal flow from the left (suppliers) to the right (customers) is what is conventionally recognized as the “supply chain” for a given product, whereas the vertical flow from the top to the bottom has often been called the “engineering chain” in recent years.

As this diagram shows, there is circulation of design information between customers and firms/suppliers. Current customers’ satisfaction is translated into product concepts, functional and structural designs, and then into process designs and actual production processes along the engineering chain. Production occurs where the vertical chain and the horizontal chain meet, where design information is transferred to the materials as media. Note that, in actual cases, the supply chain is much longer and numerous branches of vertical design information paths move down from the top.

1.2. Supply Chain Competitiveness and Robustness

Now let us discuss the *competitiveness* of sites and products, using this broad concept of manufacturing. Generally speaking, competitiveness refers to the ability to be selected. Market performance, or surface-level competitiveness, indicates the ability of a product to be selected by the customers in the market in a free-choice situation. Productive performance, or deep-level competitiveness, denotes the ability of a genba to be selected by a company as the manufacturing site that can continue operations. A product’s market performance indicators include price, delivery and overall product attractiveness, which reflect its market share, whereas a genba’s productive performance indicators measure the “goodness” (e.g., efficiency, speed and accuracy) of design information flows, including productivity, lead times and manufacturing qualities.

In the age of post-Cold-War global competition, genba sites in relatively high-wage areas, such as Japan, North America and Western Europe, have had to accelerate improvements (*kaizen*) in productive performance in order to overcome their handicaps in terms of international wage gaps vis-à-vis sites in lower-wage, emerging countries.

In this context, we regard the *supply chain competitiveness* of a given product as the productive performance not only of the focal production site but also of the entire set of sites and firms, including those dealing with product development, connected by the design information flows related to that product.

Let us now turn to the concept of *supply chain robustness*. An industrial system's *robustness* against such destructive forces as natural disasters (e.g., earthquakes, hurricanes, etc.) and man-made disasters (e.g., fires, military attacks, etc.) refers to its ability to maintain value-adding flows and minimize stoppages when destruction actually occurs. Such flow stoppages may be caused by (i) destruction of productive resources, each of which is a combination of design information and its medium, and (ii) destruction of the linkages among said resources, such as transportation systems or energy supply lines.

The anti-disaster robustness of a supply chain may be measured by its flow continuation ratios and by the shortness of its flow recovery time. As mentioned earlier, these robustness indicators are affected by various factors, including physical strength of buildings and equipment, buffer levels, as well as genba capabilities in terms of on-the-spot recovery and substitutive production. These aspects of supply chain robustness will be discussed later in this book.

It is worth noting that production stoppages at the affected facilities do not automatically involve stoppages in the supply of the products that they manufacture, as this may still continue using suppliers' product inventories, customers' material inventories, as well as inventories in the transportation pipeline or in intermediary warehouses. The available levels of inventories will depend upon whether the suppliers' inventories and shipping areas are hit by the disaster, whether transportation routes and warehouses are severely damaged, and whether the customers' material receiving areas and inventories are destroyed.

It should also be underlined that the essential element for supply chain robustness is continuation of the flow of value-carrying design information embedded in its materials as media rather than of the materials themselves. Thus, when said flow stops, one way to recover it is to detach design information (e.g., recipes and NC data) from the damaged productive resource, move it and re-embed it into other productive resources at undamaged sites. We often call this substitutive production. Moving undamaged productive resources, such as dies and operators, from disaster-affected sites to alternative locations is another way to achieve substitutive production.

As mentioned earlier, we argue that the competitiveness and the robustness of a supply chain should be analyzed concurrently, since in a scenario of post-Cold-War global competition firms often need to achieve both at the same time. In other words, today's firms and sites facing disasters need to maintain and recover not simply flows but competitive flows of value-carrying design information. It is not easy, however, to achieve this balance between competitiveness and robustness. Additional buffers for greater robustness, for example, may result in longer lead times and lower productivity. The present book will investigate how firms deal with the daunting task of balancing competitiveness with robustness.

Keeping in mind the above broad framework for analyzing manufacturing activities and supply chains, let us now discuss some key concepts related to how firms and sites may improve supply chain robustness without sacrificing their competitiveness.

2. DIAGNOSIS OF SUPPLY CHAIN WEAKNESSES

The first step to improve the robustness of a supply chain is to identify its weak links and nodes. This is similar to the case of process improvement, which often starts by identifying bottlenecks and critical paths. At least four main criteria are used to detect supply chain weaknesses: dependence, invisibility, non-substitutability and non-portability. Let us examine them in this order.

2.1. Dependence on a Critical Supplier

A firm's heavy dependence on a certain supplier's product as its main input may represent the weak link in its supply chain. Typical examples mentioned in this book include microcontrollers manufactured by Renesas (Chapter 6), brake parts affected by the Aisin Seiki fire (Chapter 5), and piston rings made by Riken (Chapter 4).

These supply chain crises have made Japanese manufacturers realize the significance of the so-called "diamond-shaped structure" of supply chains. In the automotive sector, although higher-tier parts (functional components) may be provided by more than one supplier, lower-tier parts (piece parts) are often produced by only one critical supplier, which uses unique product or process technologies. In extreme cases, all of the product assemblers in a country or most assemblers worldwide may depend on a single parts supplier. Thus, from the focal assemblers' point of view, the shape of a component's three-layer supply chain will resemble that of a diamond, with only one node, the critical supplier, at the bottom. The existence in and of itself of such technologically irreplaceable suppliers may be one of the reasons behind Japan's industrial competitiveness but, if their supplies stop after a disaster, the repercussions can be severe.

Obviously, one viable solution for the downstream firms is to alter this diamond-shaped structure by increasing the number of supply sources for the critical parts in question. However, if this means accepting lower-quality parts from technologically inferior suppliers, or if such diversification reduces the critical suppliers' economies of scale, the change may have a negative impact on the supply chain's overall competitiveness.

Another possible measure to alleviate this dependence problem is for the critical supplier itself to diversify its production sites, reducing its clients' dependence on a single factory. Let us assume that this supplier has two factories, factory 1 and factory 2, which are geographically apart, and two complementary items, A and B. The company can choose between two manufacturing strategies. First, it may opt for a flexible system, with a mixed model and small lot production, so that both factories will produce both A and B and supply them to geographically closer clients—the Toyota Way solution. In assembly and some machining operations, this approach will be more feasible.

If the nature of the production technology is such that the flexible production described above is not economically or technologically feasible, then the supplier may decide to produce A in factory 1 and B in factory 2 at times of normal production, when competitiveness matters. However, if a disaster strikes, the supplier needs to have the manufacturing capability to move design information from its damaged plant, factory 1 or 2, to a plant that was unaffected by the disaster, factory 2 or 1, and start substitutive production as soon as possible. Hence, both factories must be potentially flexible, so that they can quickly switch their systems to mixed model production during emergencies. We call this "virtual dual strategy" and we will discuss it later in this book.

Nonetheless, relying on the concentration of an input's supply from a single critical supplier may sometimes be preferable from a technological and competitive point of view, but at the same time downstream suppliers and assemblers must remain continually aware that such heavy dependence on one product/process/supplier may create weak links along the supply chain. Thus, they will need to devise appropriate precautionary measures and make disaster response plans before such a critical supplier is hit by a catastrophe.

2.2. Supply Chain Invisibility

The second supply chain weakness that became apparent after the 2011 Tohoku Earthquake is that, in complex supply chains, some small upstream (lower-tier) suppliers may be invisible to assemblers and downstream (higher-tier) suppliers, so that rescue and recovery assistance may be significantly delayed. Thus, invisible nodes along the supply chain may turn into major bottlenecks in times of disaster.

It is worth noting that stoppages in the supply of a single item, out of the roughly 30,000 parts making up a car, can bring the whole assembly line to a halt. Suppose, for example, that a part of a functional component, e.g., a small spring, is supplied by a fifth-tier supplier. Suppose also that the spring's heat treatment to increase its strength is carried out by a process subcontractor and that a consumable subsidiary material used in the heat treatment process is supplied by yet another supplier. If a disaster hits the latter seventh-tier supplier providing the consumable item—which is not included in the auto manufacturers' design information (e.g., Engineering Bill of Materials or e-BOM), since it does not remain in the final product—, it is rather difficult for assemblers to find out that said supplier's factory was devastated by a tsunami or other disaster. Indeed, this example is very close to what actually happened after the 2011 Tohoku Earthquake.

Small, consumable and yet critical parts and processes can be easily overlooked, particularly in the case of complex products such as automobiles. When the destroyed sites and facilities are invisible to downstream assemblers and suppliers, their recovery from the damage caused by a disaster may be seriously delayed, even when the downstream firms possess fast recovery assistance capabilities, simply because it takes time for the latter to identify the former in the first place.

In order for a final assembler placed downstream along the design information flow to identify such potentially weak points in advance, for example in the case of automobiles, it may not be enough to break the product design information down into its approximately 30,000 individual components, based on its Engineering Bill of Materials (e-BOM). Downstream firms should also have a thorough understanding of the information included in the Manufacturing Bill of Materials (m-BOM), which contains data regarding facilities, equipment, consumables, and other resources needed to manufacture each part at every level of the chain.

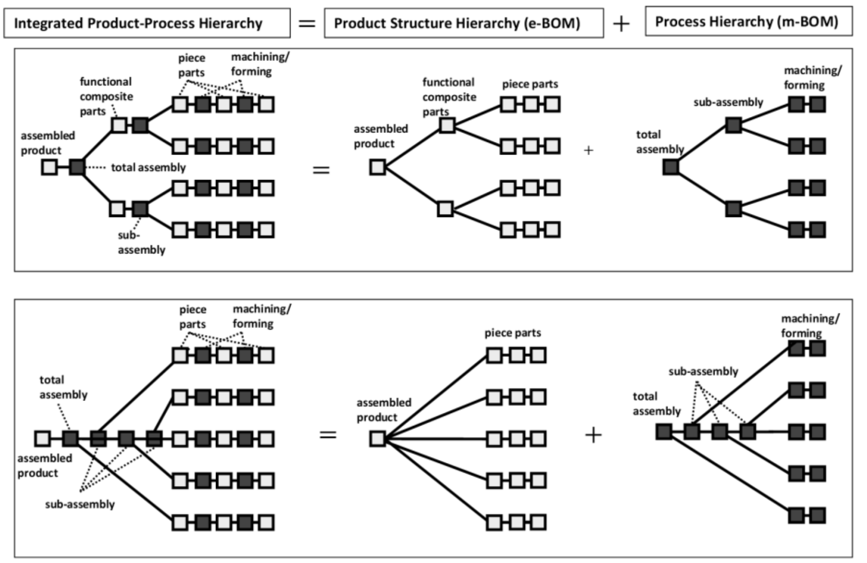

Figure 2. Complementary Structure of product and process Hierarchies.

As shown in Figure 2, such comprehensive product-process knowledge or engineering-manufacturing design information is vital for assembly companies downstream along the flow of design information, so that the information on nodes and links damaged by a disaster can be interpreted quickly and effectively.

However, the supplier system of Japan's automotive industry has traditionally been managed layer by layer, with first-tier suppliers handling the second tier, second-tier suppliers handling the third tier, and so on. For such a complex supply chain, this vertically decentralized system has actually been flexible and competitive in its own way, but it undoubtedly caused serious problems of invisibility in the aftermath of the 2011 Tohoku Earthquake. It took the Toyota Motor Corporation—known as one of the world's most effective companies in disaster damage control—over a month to identify exactly how many suppliers and sites had been affected by the Tohoku Earthquake. In an emergency, preserving the strength of the supplier system while also ensuring suppliers' information transparency, all the way to the most upstream areas (or lowest-tier levels), is certainly a difficult task. Later in this book, we will discuss how capable firms like Toyota have improved the visibility of their suppliers by developing a database for the whole supply chain.

2.3. Design Information Non-Substitutability

The third criterion to identify supply chain weaknesses is non-substitutability. When it is extremely difficult to replace some of the components, materials or processes of a given product with substitutes, such items and sites are recognized as non-substitutable, with relatively high supply risks in times of emergency. As mentioned in Chapter 1, a non-substitutable item along the supply chain often contains design information that is specific to a particular customer's product (e.g., customer-product specific) and is developed and/or produced by means of special processes unique to a specific supplier (e.g., supplier-process specific). Hence, the supplier cannot change the customer and, at the same time, the customer cannot replace the supplier. So, if one party stops its operations due to a disaster, the other party is seriously affected in economic terms, because it would be difficult for the purchaser to replace the item by switching to other standardized parts or other suppliers of the same item.

Supply chain weaknesses due to the aforementioned product-process non-substitutability represent an even bigger problem in the case of coordination-intensive products or products with integral architecture that are developed and produced by coordination-rich genba sites, such as highly-functional automobiles (Fujimoto 1999, 2007, 2014a). And it is known that, also due to historical reasons, competitive genba sites in Japan's manufacturing industries have tended to be endowed with coordination capabilities, or teamwork of multi-skilled workers, and to enjoy design-based comparative advantages in coordination-intensive or integral architecture products (Fujimoto 2007, 2012, 2014b). It should be observed here that integral products usually consist of product-specific parts, as a result of design optimization, and that highly coordinative processes tend to become unique or supplier-specific. This has been the competitive situation in post-Cold-War Japan, whose trade goods industries have been hit by disasters several times.

The coordinative capabilities of Japan's competitive sectors have been accumulated not only within each manufacturer but also between manufacturers and suppliers—e.g., supply chain competitiveness with close coordination and collaborative problem solving between assemblers and parts suppliers (Asanuma 1989, Cusumano and Takeishi 1991, Dyer 1994, Nishiguchi 1994, Fujimoto, 2001). The joint development of product-specific parts by assemblers and suppliers has been statistically identified as one of the Japanese automobile makers' competitive advantages (Clark and Fujimoto 1991).

Here is a key dilemma regarding supply chain competitiveness and robustness. As mentioned above, the Japanese automotive industry has built relatively strong coordinative capabilities at its genba and has enjoyed design-based competitive advantages in relatively integral products, such as automobiles, but its product-process specificity, as a result of its product architectures and genba's capabilities, has also become a source of supply chain weakness, due to product-process non-substitutability. In the event of a disaster, this may cause serious vulnerabilities along the supply chain. The case of the microcontrollers discussed in Chapter 1 is a typical example of such non-substitutability.

There have been situations in which supply chain disruptions caused by non-substitutable parts were expected and the practice of ordering parts with the same design information from more than one supplier (e.g., multiple sourcing) has been implemented in various industries. However, this usually occurs when detailed parts designs are provided by automobile assemblers, e.g., the so-called "detail-controlled parts" or "drawing-provided parts" (Clark and Fujimoto 1991). If an assembler and a supplier jointly develop basic and detailed design information, e.g., "black-box parts" or "drawing-approved parts", then components having that design information can only be ordered from that single supplier, as the ownership rights of their detailed designs belong to said supplier (Fujimoto 1999, 2001). Moreover, for effective mass production and from the perspective of cost competitiveness, it is desirable to concentrate orders by placing them with a single company.

As a result of this concentration of ordering from a single company, since the parts are not standardized but product-specific, there are obviously no supply companies able to provide substitute parts when a disaster strikes. Thus, in the case of non-substitutable parts, downstream firms have to tackle the serious issue of how to ensure that the supply chain can recover from crises caused by disasters.

2.4. Design Information Non-portability

The fourth vulnerability of supply chains is the lack of portability of design information, or the problem of whether the design information embedded in a certain productive resource in a damaged manufacturing plant can be detached from it and transferred to an alternative site after a disaster.

In the case of mechanical products, for example, the stamping die attached to a destroyed press machine can be removed and transferred to another press, or the drilling tools from a damaged machining plant can be moved to another plant, along with blueprints and numerical data. Thus, the portability of design information is important for the quick recovery of damaged factories, and the lack of such portability can cause serious supply chain disruptions.

As for chemical plants, when operations are suspended because of an accident or a disaster, the key design information for controlling the process—the recipe (operating procedures)—often needs to be moved to an undamaged plant, where the equipment and recipe undergo quick "recipe amalgamation," e.g., they are adjusted to match each other. An example of this, described in Chapter 1, is what happened to Kaneka in March 2011.

However, when dealing with some technologically advanced production lines, such as those for the manufacturing of semiconductors, transferring the product-specific circuit design information (mask and recipe) to other equipment during emergency evacuation is a technically difficult procedure. If design information cannot be easily separated from the production process (e.g., the information is "sticky"), quick resumption of substitutive production is not easy, because it may be necessary to move the whole production equipment rather than a part of it. As a result, the supply chain recovery team may have no choice but to opt for "recovery on the spot," or reopening of the affected supply chain by fixing the damaged process itself. This is what happened at Riken following the 2007 Chuetsu Offshore Earthquake and Renesas's Naka Plant in the aftermath of the 2011 Tohoku Earthquake.

Thus, in certain types of industries and genba, particularly in advanced capital-equipment-intensive industries with high-precision operations, weak spots tend to develop along the supply chain where there are non-portable dies, recipes, masks, NC programs and so on, which are difficult to detach from the damaged production process. Consequently, non-portability of design information becomes a source of supply chain weakness.

In summary, in order to evaluate vulnerabilities ahead of actual disasters, a deliberate *supply chain diagnosis* is indispensable, especially in relation to: purchasers' *dependence* on specific suppliers, suppliers' *invisibility* to downstream firms, *non-substitutability* of design information embedded in productive resources, and *non-portability* of design information attached to the production equipment and other resources. Firms and industries aiming to prepare for future disasters will carry out and frequently update diagnoses of their entire supply chains, identify potential weak nodes or links and concentrate on the vulnerable spots identified to develop systematic action plans. Such plans will involve physically strengthening problematic processes, conducting anti-disaster drills at multiple genba sites, including the suppliers,' as well as making preparations for quick recovery from damage and fast reopening of the supply chain.

However, making precise diagnoses and implementing the abovementioned plans is no simple task when both supply chains and design information are complex. We will discuss the matter further in later parts of this book by presenting various case analyses.

3. Conventional Post-Disaster Measures and their Limits

3.1. Considering Post-Disaster Measures in Advance

Having discussed supply chain diagnosis, we can now move on to actions plans for preventing or alleviating supply chain damage in case of actual disasters.

After completing a detailed diagnosis of a supply chain's vulnerability and robustness, those who are responsible for its management need to carry out the following tasks, at least: (1) consider preventative measures before an actual disaster strikes and build them into the supply chain design; (2) determine procedures to be implemented in response to disasters and adopt them as rules before the next catastrophe strikes; (3) provide quick and effective response after an actual disaster in all the cases not anticipated in (1) and (2) above. In other words, in preparation for, and in response to, the next big disaster, the following three measures are needed: (1) prior determination of precautionary measures, (2) prior determination of post-disaster measures, and (3) post-disaster determination of post-disaster measures. As described later, item 2 (careful prior determination of post-disaster measures) is considered to be particularly important, since it is not reasonable to assume that supply chain damage can be avoided altogether when a major disaster occurs.

Since Japan has been a natural-disaster-prone industrialized country for so many years, there has been a lot of discussion about how to alleviate damage from future disasters. Besides the straightforward measure of making production processes and buildings physically more robust, some of the traditional approaches to anti-disaster efforts have included: (1) adding buffer inventories; (2) switching from product-specific to standard parts; (3) adding back-up production lines (dualization); (4) moving entire production facilities to seemingly less disaster-prone countries. There is a certain logic behind each of these approaches—and each has its limits, too. Let us examine them one by one in the above order.

3.2. Adding Buffer Inventories

One of the most frequently discussed measures in response to supply chain disruptions concerns increasing inventories of raw materials, work-in-process, and final products. A basic concept of inventory management theory for enhanced competitiveness in normal times is that of keeping appropriate levels of safety or buffer inventories at a location that is suitable for both manufacturing processes and supply chains. During normal production, the target levels of such inventories can be estimated by taking into account inventory costs and risks of under-supply or over-demand, assuming that they can be determined by assigning a probability to each event. The elements affecting said probability may include sudden increases in orders, traffic congestions, or snowstorms in specific problematic areas.

Following the above approach, the Toyota Production System (TPS), or the Just-In-Time (JIT) system as its subsystem, does not advocate the complete elimination of all inventories but only of non-functional inventories, seen as waste (*muda*). In fact, without a certain amount of inventories, neither TPS nor JIT would work properly. Thus, in normal times, genba and firms, with their functional requirements and constraints, try to achieve appropriate levels of inventories in the right location in order to maintain competitiveness and fulfill their supply responsibilities toward their customers.

Facing the intensification of global competition in the post-Cold-War era, many Japanese manufacturing sites and firms have had to intensify their capability-building efforts to ensure "good flows of good design information to customers", including tighter inventory management. Besides, when wages in lower-wage emerging countries, such as China, started to soar (around 2005) and the unlimited supply of labor force from agricultural to industrial regions started to shrink (the so-called "Lewis turning point," after Nobel Prize Laureate Prof. Lewis's theory developed in the 1950s: Lewis, 1954), the nature of global competition itself soon shifted from simple cost competition to *global capability-building competition*. This means that manufacturing sites all over the world, including China and India, now need to continuously improve their productivity, quality and lead times in order to survive as exporting factories. In other words, as the international wage gap between advanced and major emerging countries narrows, factories in low-wage countries can no longer rely solely on their low wages. Proper inventory management is becoming increasingly important worldwide as part of the global capability-building competition.

If this is the case in the main manufacturing countries today, then the following guidelines should be applied to inventory management. First, careless addition of inventories having negative effects on productive performance (lead times, productivity and quality) should be avoided, in view of the intensifying global capability-building competition. In principle, the level of buffer inventories at any manufacturing site should be determined not only by considering anti-disaster preparations but also by taking into account both robustness against disasters and competitiveness against international rivals in a balanced way. Hence, when planning supply chain inventory systems, we should consider improving competitiveness, as well as preparing for reasonably predictable supply chain disruptions, rather than focusing on robustness against unprecedented disasters, because the latter are so unpredictable that their likelihood cannot be estimated. If we are trapped by a "huge-disaster-first mentality", the result might be unlimited piling up of "just in case" inventories, stemming from emotional anxiety rather than rational analysis of the reality.

Without a doubt, when overwhelmed by the tragedy of the 2011 Tohoku Earthquake, many Japanese were emotionally inclined toward "huge-disaster-first" thinking. Yet, considering the intensity of global competition, we should keep in mind that anti-disaster measures relying solely on inventories, to the detriment of competitiveness, may prove dangerous for the survival of the firms and sites in question. Hence, this book emphasizes capability building rather than adding buffers as a primary anti-disaster measure.

An exceptional case, in which we can discuss competitiveness and robustness separately, is the case of food reserves and other commodities, such as water, fuel, toiletry goods and medical supplies, that may be stockpiled by households, communities, firms and local governments in preparation for disasters. These stockpiles at the downstream end of supply chains are regarded economically as consumption, as opposed to inventories. Therefore, households, firms and communities will set their own levels of such emergency reserves by assessing their demand and lead times for emergency rescue and supply lines recovery, without taking competitiveness factors into account.

As for the firms and sites along the supply chains, the abovementioned decisions about emergency reserves made at the downstream end will affect their target lead times for supply chain recovery after disasters. If, for example, a medical supply manufacturer estimates that the available reserves of item A will be sufficient for at least three weeks when a major disaster hits an area in Japan, three weeks will become the target recovery lead time of this item's supply chain. The burden of responsibility that the companies supplying these products have to bear is rather heavy in times of emergency, so they need to make a reasonably accurate assessment of their target supply recovery lead times before and after disasters. In the aftermath of the 2011 Tohoku Earthquake, for instance, Terumo, a leading medical supply manufacturer in Japan, promptly requested emergency imports of injectors, whose domestic supply shortage was anticipated, from its factory in the Philippines, and the government assisted the firm by temporarily relaxing medical import regulations. Kaneka, whose Kashima plant was damaged by the March 2011 tsunami, quickly arranged substitutive production of vinyl chloride for infusion solution bags at its Takasago main plant, since demand for such products soared after the earthquake.

To sum up, merely piling up inventories in fearful anticipation of future disasters to the detriment of supply chain competitiveness should be avoided, despite our human inclination toward a "disaster-first mentality", reinforced by witnessing huge tragedies. Thus, this volume emphasizes that the primary measure to enhance anti-disaster supply chain robustness is continuous capability-building for quicker and effective recovery of the flows of design information to customers, rather than stockpiling buffer inventories.

When major disasters cause supply chain disruptions, both Japanese and Western media outlets point out as a weakness the Just-in-Time theory of reducing inventories, but in most cases it turns out that such simplistic views are beside the point. It is certainly true that all supply chains need inventories, but their levels should be decided primarily from the standpoint of everyday competition.

3.3. Switching to Standardized or Common Parts

The 2011 Tohoku Earthquake clearly revealed that irreplaceable product-specific materials, such as microcontrollers, certain functional chemicals and certain high-performance components, cause supply chains to be vulnerable. A seemingly easy solution to this problem may be the use of more standardized parts and materials, which can be supplied by multiple sources to multiple customers without sacrificing scale economies. Such standardized or commonized items are more substitutable, compared with the aforementioned product-process specific parts, and can thereby alleviate supply chain weaknesses in times of disasters.

When firms opt for this choice, however, they should take into account the architectures and capabilities of their products and genba. In cases when customers' functional requirements are high and socio-technical constraints are severe for a given product, its macro architecture tends to become more integral, with higher levels of design optimization and more customer-product-specific parts (Ulrich 1995, Fujimoto 2007). If the assembler and the supplier possess joint problem-solving capabilities, they will enjoy competitive advantages by working together, but the parts developed will become more supplier-process-specific (Clark and Fujimoto 1991, Nishiguchi 1994). Thus, provided that there are competition-based reasons why a company adopted a certain type of micro-architecture, or product-process-specific parts, replacement with standard parts should be carefully evaluated.

It is true that Japanese manufacturers tend to overuse their relatively rich coordinative capabilities, thus becoming trapped by over-design and over-quality, which means that product design and manufacturing quality become too high when compared with costs, as well as prices for the main customers. Based on the above reflections, since the 1990s, Japanese automobile assemblers have concentrated their efforts on value engineering (VE), e.g., simplifying product structures while keeping product functions, including reductions in the number of parts and adoption of more common parts and modules within each company. For example, the number of bolts in a Toyota luxury car was reduced from about 5,000 to 4,000 in the 1990s.

Yet, the use of industry standard parts by Japanese auto firms has remained quite limited (much less than 10%). Even when common parts designs are adopted across different products, they are common only to a single company/group (e.g., closed-modular, as opposed to open architecture). Moreover, assemblers and suppliers have continued to develop parts jointly (e.g., black box parts), so any common parts introduced are still provided by a single supplier (Fujimoto 2001). Thus, the firms' efforts toward simplifying their products and communizing their parts have not resulted in higher substitutability.

The Japanese auto makers and first-tier suppliers have also significantly expanded their overseas production since the 1990s. While domestic automobile production was stable, at around 10 million units, overseas production grew from about three million in 1990 to 18 million in 2015. This means that similar models using common parts may be produced both in Japan and overseas, creating complex global supply chains.

Such supply chain globalization can have either positive or negative effects on supply chain robustness. Suppose that component C is a common part for product models VA and VB, produced in countries A and B respectively. If C is locally produced in both counties to reduce transportation costs, components CA and CB have identical design information and, when CA factory is damaged by a disaster, CB factory can substitute it, and vice versa, enhancing the robustness of this global supply chain. Conversely, if component C is produced only in county A due to comparative advantages, the assembly factories in both country A and country B will be seriously affected when CA factory stops operations due to a disaster, thus reducing supply chain robustness. So, supply chain globalization can have either a positive or negative impact on anti-disaster robustness—and no definitive conclusions can be drawn.

To sum up, the choices made by competing firms regarding product architectures, parts commonality, supplier involvement, overseas production, overseas purchasing, parts localization, and so on, can have both positive and negative effects on supply chain robustness and weakness. This implies that, if they decide to adopt either (i) industry standard parts shared with other firms or (ii) common parts shared by their products and factories, such decisions can be either compatible or conflicting with their other competitive strategies mentioned above.

In this situation, as in the case of adding buffers, we argue that firms should give first priority to competitiveness rather than robustness. That is, when firms along the supply chain consider a plan for parts standardization or commonization from the point of view of supply chain robustness against disasters, said plan should be adopted only when it is compatible with their competitive strategies related to product development, product architectures, global production/purchasing, and so on.

3.4. Supply Chains Dualization

Another anti-disaster measure discussed in the past, particularly after the 2011 Tohoku Earthquake, is duplication of identical production lines in mutually distant areas. After witnessing the destructive power of a huge earthquake and tsunami, either first hand or through media broadcasts and the Internet, the natural reaction of industrial practitioners, including foreign buyers, was to demand duplication of production lines (dual tooling) and/or increases in the number of substitutable suppliers (dual sourcing). For example, the manager of a factory located in Eastern Japan, outside the area affected by the 2011 Tohoku Earthquake, told us that a buyer from a European customer company came to him soon after the disaster stating that his firm would terminate the existing contracts unless the Japanese firm immediately set up an identical production line in the Western part of Japan.

Considering the fact that this earthquake was an unprecedentedly huge disaster, which happened in the middle of global competition, the panic reaction of the aforementioned buyer is understandable, but firms should never lose sight of the issue of balancing competitiveness and robustness.

It is true that having multiple copies of substitutable equipment and production lines containing the same design information in separate regions is an extremely safe way to improve supply chain robustness. This is a particularly popular approach among buyer companies, especially when, as mentioned above, there are concerns about high dependency, low substitutability or low portability of products/processes along the supply chain. Yet, this approach may also have a major negative impact on that supply chain’s competitiveness, particularly on cost, so careful evaluation of both pros and cons is needed.

More specifically, whether duplication of identical production lines makes sense depends upon certain conditions, including demand growth, production technologies, price sensitivity and social responsibility. In conclusion, dualization of domestic production lines or suppliers could be justified only under the conditions detailed below.

First, if worldwide demand for the product in question is growing, the additional production capacity will be absorbed by that growth, without heavy repercussions on cost. Second, if certain new production technologies decrease the production line’s minimum efficient scale, dual tooling may become economically feasible. Third, if the differentiated nature of the product is such that its non-price competitiveness is significant enough to overcome the cost-price-up effect of dual tooling, then this may be implemented. Fourth, if, for some reason, the product is so critical for society at large that social responsibility to re-supply it immediately is considerable even after a huge disaster, production line dualization may also make sense.

Conversely, if the economic situation is such that demand growth for this product is not expected, dual tooling will result in significant per-unit fixed costs increases due to lower utilization ratios. Unless new and compact production technologies can make up for this fixed costs burden, or the product is so differentiated that its price increase is accepted by the market, or company managers decide to go for dual tooling anyway for reasons related to social responsibility, the significantly higher unit cost brought about by dualization will not be economically acceptable to the firm.

For example, what if a production line in Japan supplying automotive parts mainly domestically is damaged by a disaster and the quick decision is made to build a new production line? Assuming rapid domestic demand growth is not predicted, doubling the production capacity by adding an identical production line, equipment, and dies, particularly in the case of large capital intensive processes, would immediately lead to a reduction in productivity and an increase in fixed per-product costs. If, in addition, cost competition against factories in lower-wage emerging nations is intense, this decision could prove fatal to both facilities.

When actual duplication of production lines is not economically feasible, there is an alternative way to implement substitutive production in times of disaster, e.g., *virtual dualization* of production lines. This method refers to optimizing the combination of the firm's multiple products with its multiple factories and production lines in normal times with the aim of improving competitiveness, while also accumulating capabilities for substitutive production in the various factories and lines, so that, whenever necessary, the products (design information) can be moved from a damaged genba to an intact facility by making the production line in the latter a temporary mixed model line. Thus, if a production line is destroyed, transferring the critical design information to another product's existing production line—virtual dualization—may be an alternative measure to actual production line dualization, and this idea will be discussed in more detail later in the book.

3.5. Moving Factories to Less Disaster-Prone Locations

The fourth possible choice is to close down the factory damaged by the disaster and move its production capacity to less disaster-prone locations.

The definition of "less disaster-prone" may differ depending upon the location. Future earthquakes can happen anywhere in Japan, so overseas sites should be considered in this case. Also, elevated or inland locations will certainly be less tsunami-prone. Manmade disasters, such as fires and plant explosions, are equally unpredictable, but rescue and recovery capabilities may vary across regions and countries. Keeping away from volcanoes that may one day erupt is another valid concern. For instance, a Japanese manufacturing firm with three main domestic factories around Mt. Fuji, whose probability of future eruption is not zero, may decide to build a new domestic factory at a relatively volcano-free location in the Western part of Japan. Lastly, wars and terrorism can affect any part of today's world, but their related risks will be different from county to country.

Some plants actually moved after the 2011 Tohoku Earthquake. When the Fukushima Daiichi (Number 1) Nuclear Plant was destroyed by the tsunami, the factories located in the long-term evacuation area, which is inaccessible due to radioactive contamination, had no choice but to move their entire facilities to other locations, either temporarily or permanently. A factory of sinter metal materials located near the coast in the city of Hachinohe also relocated its main production processes to a site with higher elevation in the same area (Chapter 6).

Another situation is that of factories damaged by a disaster that are losing competitiveness anyway, due to high-cost structures, obsolete production technologies, old buildings, and so on. In such cases, disasters may simply accelerate the firms' decision to close down the affected facilities and build more competitive ones in the same place or at better locations elsewhere. When this happens, the damaged plant may eventually disappear or shrink. Note here that 2011 was a year of very strong appreciation of the yen (about 80 yen per dollar), characterized by fierce arguments in the media about the potential, massive hollowing out of the Japanese manufacturing industry, although this did not happen due to rapid wage increases in emerging countries and continued capability-building by Japan's domestic genba.

The argument put forward in this chapter—priority to competitiveness criteria over disaster-robustness criteria—can be applied to the above situation too. In other words, if a production line damaged by a disaster was already considered uncompetitive in the long run, the company should pursue global optimization by speeding up its closure or relocation. In more general terms, when international trade is reasonably free, global competition is intense and competitive environments are changing, there are always some domestic industries that are losing comparative advantages, while others are gaining advantages. When a disaster strikes, the factories in disadvantageous sectors are more likely to be moved to other countries.

In addition, if a damaged plant uses production technologies that are obsolete and/or production equipment that is already depreciated, it may be closed down after a disaster and moved to a more competitive and less disaster-prone location, including low-wage emerging countries.

Nonetheless, the above decisions must always be based on rational and long-term thinking, as they may involve global and long-range capital investments. It is worth underlining again that the 2011 Earthquake occurred in a period of very high appreciation of the yen, and it was just a few years after the US financial crisis and worldwide recession. As a result, this huge natural disaster added momentum to the psychological pessimism already prevailing in Japan's media, society and industrial environments, so that Japanese firms' decision makers were more likely to come to emotional or shortsighted decisions regarding global plant locations.

Fortunately, there has been no massive exodus of factories from the Tohoku area. The period of high appreciation of the yen (80 yen per dollar) was over in a few years, the international wage gap vis-à-vis China—a handicap for Japanese factories—narrowed, and restoration of the Tohoku industries is making slow but steady progress.

The managers of the genba sites affected by the 2011 Tohoku tragedy have tended to focus only on earthquake-related dangers, but they ought to calmly consider that there are many different types of risks in the world. Another earthquake happening in the disaster-struck Tohoku region is certainly a possibility, but threats may come from a range of other situations, such as wars and terrorism, civil strife, or confiscation occurring in foreign countries. Indeed, risks may arise anywhere at any time.

Before the 2011 Earthquake, automobile companies from the Toyota Group, such as Toyota Motor Tohoku, had moved some of their assembly and component plants to the Tohoku Region (the North-Eastern part of Japan's main island). Quite ironically, one of the motivations behind this shift was to disperse the Toyota Group's domestic production base, which was highly concentrated in the central part of Japan, where scientist predict that major earthquakes may strike at any moment. At present, the automobile supply chains in Tohoku still suffer from a few problems, among which an insufficient number of major parts plants and geographically dispersed ports, but the area is said to have advantages in terms of stable and high-quality labor force.

Construction of a regional supply chain such as this requires long-term efforts and sound judgment. A large disaster may indeed change some of the conditions to be considered, but the efforts made should not be affected by short-sighted or emotionally pessimistic thinking triggered by the psychological impact of catastrophic events.

CONCLUSION: BUILDING CAPABILITIES FOR ANTI-DISASTER ROBUSTNESS

This chapter explored how supply chain competitiveness and robustness can be analyzed. First, it introduced a broadly defined concept of manufacturing (or monozukuri) that emphasizes the creation of competitive flows of value-carrying design information to the customers. Within this framework, the *competitiveness* of genba (manufacturing sites) and supply chains was defined as the “goodness” of design information flows, which includes their speed (lead times), efficiency (productivity) and accuracy (quality), whereas the anti-disaster *robustness* of supply chains was defined as the degree of continuity and the shortness of stoppages affecting design information flows to the customers.

We then focused on key criteria that may be used in the diagnosis of supply chain weaknesses: (i) *dependence* on a critical supplier, (ii) supply chain *invisibility*, (iii) design information *non-substitutability*, and (iv) its *non-portability*. We argued that firms concerned about future major disasters should concentrate their efforts on the weak nodes and links displaying the above characteristics.

Next, we investigated conventional measures for improving supply chain robustness and their limits: (1) adding buffer inventories, (2) adopting standard/common parts, (3) dualizing production processes, and (4) moving factories to less disaster-prone locations. We explained that firms facing intense global competition should adopt these conventional measures only when they are compatible with the criterion of preserving and enhancing competitiveness.

We may summarize these conventional remedies by applying the design information approach presented in this chapter (Figure 1). Let us start from a simplified design information flow map (Figure 3).

We can now add the four conventional measures for enhancing anti-disaster robustness to the above design information flow map or value stream map, as shown in Figure 4. Let us now study this map. Suppose that a disaster hit an automobile component factory causing the damage shown in the black circles. Tools and equipment were destroyed and production, e.g., design information flows, was stopped (shown as in Figure 4).

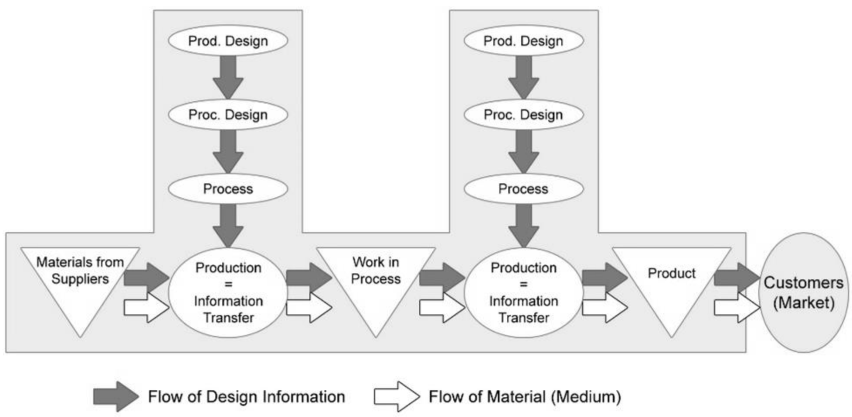

Figure 3. Supply Chain as Flow of Design Information.

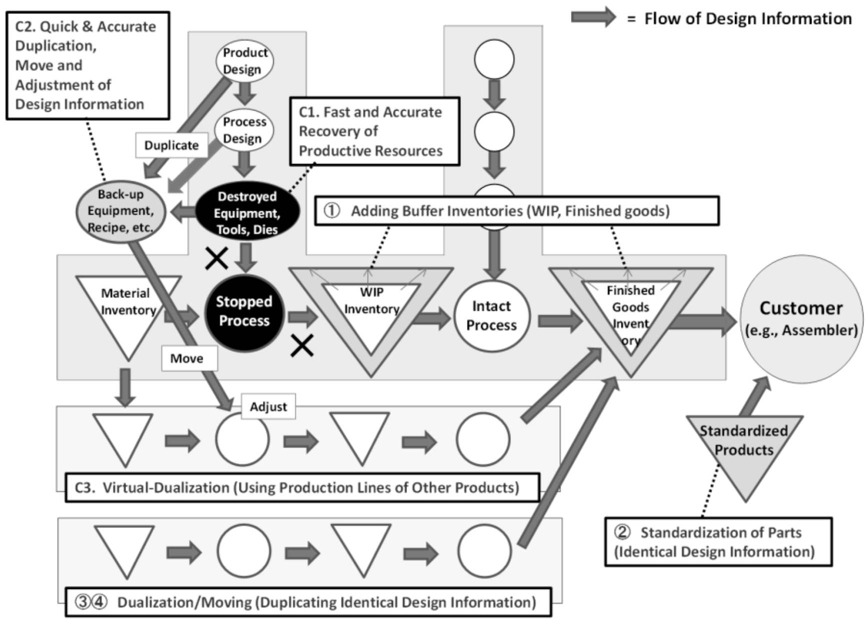

Figure 4. Measures of Supply Chain Recovery.

For the sake of simplicity, we focus only on the flows of design information to the customer, shown as arrows in Figure 4. The primary goal of a supply chain in this situation is to maximize the continuity of flows to the customer, on the far right of Figure 4, and to minimize supply stoppages.

A viable approach to achieve this would be a combination of the following: first, using buffer inventories to buy time for recovery; second, finding alternative paths of design information flows to bypass the point where destruction occurred; third, recovering the damaged process itself quickly and effectively, as the arrows in this diagram suggest.

All of the conventional measures to enhance supply chain robustness discussed in this chapter are shown in Figure 4.

1. *Buffer Inventories*: The affected supplier will be able to carry on supplying the customer by using its finished goods inventories and even continue production by using work-in-process (WIP) inventories downstream of the damaged equipment and process, as long as these inventories are intact. The more the inventories, the longer the lead times for recovery that the customer will be willing to accept.
2. *Product standardization:* If, for whatever reason, the affected parts had already been standardized within the industry before the disaster, the customer can simply find other sources of identically designed parts. In other words, the damaged item in question is highly substitutable.
3. *Process dualization:* If, at the time of the disaster, the supplier had already built multiple production lines manufacturing products of identical design (e.g., process dualization), including subcontractors and overseas factories, these alternative processes can be used, as long as they provide for temporary production expansion.
4. *Process relocation:* If there are valid reasons for the firm's management to shut down the damaged process altogether, then alternative production sites or a newly built factory may permanently take over production of the item in question.

Again, this book argues that, amidst intense global competition, the above measures are all acceptable, as long as they are compatible with ensuring the competitiveness of both suppliers and supply chains, otherwise firms will need to seek other solutions. As suggested earlier, the key to facing disaster situations is continuous capability building for faster recovery of the damaged locations and substitutive production. The capability-based measures for enhancing supply chain robustness, also indicated in Figure 4, are: building and maintaining capabilities for quick recovery (C1), design information transfer and (C2) management of “virtual dual” operations (C3).

C1: Recovery on the Spot: The first type of capability-building regards fast and accurate on-the-spot recovery of the damaged processes and other productive resources. This is conceptually simple, but rather difficult to implement. Quick recovery requires at least the following: quick dispatching of rescue-recovery teams from the headquarters and customers, quick and accurate assessment of damage, quick creation of organizational and leadership structures for recovery operations, and quick and well-coordinated implementation of the recovery activities.

C2: Design Information Transfer: The second measure involves effective transfer of the affected design information to an unaffected location. This requires quick duplication of product-process design information of the damaged tools and equipment, quick transfer of such information to the designated place of substitutive production, and quick adjustment of the design information to the equipment at the alternative production lines. In order to effectively duplicate, move and adjust the design information, high-level cross-functional and cross-firm coordination is needed, as suggested by our case studies.

C3: Managing Virtual-Dual Processes: Regarding the alternative locations for substitutive production receiving the aforementioned design information, they need to possess the appropriate manufacturing capabilities to establish stable and competitive flows of design information to the customers as quickly as possible. Such capabilities for the management of virtual-dual operations are required not only at the firm’s main and/or national factories, usually characterized by greater flexibility and coordinative skills for historical reasons, but also at other domestic and overseas factories, since future disasters may hit any factory of the firm’s global plant network and supply chains.

In the rest of the present book, we will pay special attention to these and other aspects of firms and genba’s capability-building efforts for effective response to actual disasters, as well as for improving their supply chain robustness before and after major catastrophes. As mentioned earlier, we stress the importance of the capability-building side of firms’ anti-disaster activities, rather than buffers, standardization and dualization. This is partly because capability-building can often lead to improvements in supply chain competitiveness and robustness at the same time, and partly because buffers, product standardization and process dualization for the sake of anti-disaster robustness are often incompatible with supply chain competitiveness.

By investigating several in-depth cases, the following chapters will deal with how, in the middle of post-Cold-War global competition, some Japanese manufacturing firms in the trade goods industries struggled and survived when their manufacturing sites were hit by large-scale disasters. We will focus particularly on how these firms built and implemented their anti-disaster capabilities in emergency situations.

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