# Lessons for On-The-Spot Recovery:
# Riken and the 2007 Chuetsu Offshore Earthquake

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Daniel Arturo Heller
Faculty of Business Administration
Graduate School of International Social Sciences
Yokohama National University, Yokohama, Japan
hidanielheller@me.com

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Yokohama National University

## 1. Introduction

When a production site faces severe disruption due to a natural or human-induced disaster, human lives are put at risk. Protecting people working at a plant must be the primary focus of management whenever a disaster strikes. In the case of a disaster such as an earthquake where the surrounding community is also severely disrupted, a firm must also do all it can to support the recovery of its local community. Yet beyond these paramount concerns, a firm also has a moral and probably also a clear legal obligation to make every reasonable effort to mitigate any hardship that a disrupted site imposes on its customers and suppliers.

A firm that is faced with a sudden and severe disruption at its production site needs to restore the flow of finished goods as quickly as possible. This can be done by recovering production capacity at the disrupted site (on-the-spot recovery), which should always be the default choice (as long as the disruption was not caused by the site's own egregious fault), in order to curb any possible opportunistic behavior from industrial customers that would seek to take advantage of a disrupted firm's plight. However, when necessary, restoring the flow of finished goods may also be done by shifting production elsewhere (substitutive production), or some combination of on-the-spot recovery and substitutive production.

Whitney et al. (2014) speculates that after a severe disruption on-the-spot recovery will be more commonly observed than substitutive production for most industrial products due to the high levels of specialized production equipment found in most plants. Specialization means that production assets are specifically created to manufacture a particular product or products and cannot easily be used for other purposes. The higher this asset specificity (provided it is necessary to meet product and not simply production process specifications), the harder it will generally be to pursue a diversification strategy, such as substitutive production. Thus, when there is such high asset specificity, it will be more likely that a firm will seek to pursue on-the-spot recovery, except in cases where the damage caused by the disaster is catastrophic.

While research is needed to determine if, and if so the degree to which, on-the-spot recovery is in fact more common than substitutive production, there are clearly many cases of on-the-spot recovery documented in the literature (Sheffi 2005, Tomlin 2006, Tomlin and Wang 2010, Whitney et al. 2013). Yet, at the same time, few detailed case studies of actual on-the-spot recoveries exist, which may be due to the difficulty that researchers face in obtaining such data from companies that are often reluctant to share their disaster experiences, especially where there is loss of life.

The lack of detailed real-world case studies of disaster recoveries is unfortunate because such studies can provide the practical guidance that companies need to minimize human, physical, and financial losses from disasters. The present paper seeks to address this deficiency in the literature by presenting the 2007 Chuetsu Offshore earthquake recovery experience of Riken Corporation and answering the following research question: What does the Riken Case tell us about the characteristics of effective management of on-the-spot recovery at a severely disrupted production site, and how can such characteristics be reproduced at industrial sites in general?

The paper is organized as follows. First, we present the research methodology used to gather the case study's data, including some background information on Riken and its main product, piston rings. Next, we outline the company's pre-disaster preparations. Then, we describe the scale of the disruption that occurred after the 2007 earthquake, as well as the recovery effort and results. Finally, we analyze the case to distill the lessons that it offers for on-the-spot recovery of production sites in general.

To summarize the paper's findings, the first lesson that can be learned from the Riken case is the rather obvious but all too often overlooked necessity for companies to take basic measures of disaster preparedness, in order to minimize the risk to life and property. The second lesson relates to production sites where the production equipment has high asset specificity. In such cases, it will be difficult to pursue substitutive production after a severe disruption. If the supply chain also features low inventory levels of the finished goods produced by the disrupted site, then rapid on-the-spot recovery will be an urgent necessity. Recovery assistance teams sent to a disrupted site by external stakeholders, such as industrial customers and suppliers, can speed up the recovery effort if there is a high level of trust between the disrupted firm and such stakeholders.

Trust between Riken and its external stakeholders was built up over a long history of cooperative interaction. Sustained efforts over many years by Riken's shop floor personnel and engineers to build daily operational excellence in collaboration with the company's automotive customers and suppliers seem to have been a critical factor in enabling quick on-the-spot recovery of Riken's production lines following the 2007 earthquake.

## 2. Research Methodology

This paper probes how Riken's piston ring manufacturing facilities recovered from the Chuetsu Offshore Earthquake that struck in the Japan Sea near Niigata Prefecture on July 2007. Data collection and case analysis follows Yin (1994), which recommends case-study research for studying a contemporary event in its real-life context when the boundary between the phenomenon and its context are blurred. A key tool used in case-study research is triangulation from multiple sources of evidence. The following data sources were used to research the Riken case.

The author took part in a five-year (2010-2014) research project on supply chain disruption and recovery, with Daniel E. Whitney and Jianxi Luo, that collected data from primary and secondary sources about the experience of Riken Corporation when its piston ring manufacturing facility was severely disrupted by the 2007 earthquake. The findings of this research project are contained in Whitney et al. (2013, 2014).

The author participated in three visits to Riken to collect the primary data used in the present paper. The first visit on March 23, 2010 was to Riken's Kashiwazaki Plant that was disrupted by the 2007 earthquake. The half-day visit began with an overview presentation, followed by a plant tour of some of the piston ring manufacturing facilities that were damaged by the earthquake in 2007, and ended with an extensive question and answer session with the head of production administration, who was personally involved in the disruption recovery. After the visit, the author had several follow-up interactions with this manager by email. Additionally, the author was given copies of Riken (2007a, 2007b), which together with Yoshimura (2008) are the source of many of the case details presented here.

The author's second visit to Riken was on July 13, 2012. This time the visit was to Riken's Kumagaya Plant, which is located 150 kilometers away from Kashiwazaki City, yet where a two-hour group interview specifically about the 2007 earthquake recovery was conducted with the following four people, all of whom were directly involved in the disruption recovery: the plant manager, the head of the precision manufacturing department, the head of production administration, and a senior engineer in the product development division. A senior manager in quality control also participated in the discussion, but he had joined Riken after 2007.

The author's third visit to Riken was on April 20, 2015, also to the Kashiwazaki Plant, to have a plant tour and discussion together with a group of approximately 20 Japanese auto industry practitioners and analysts who sought to learn lessons from Riken's recovery experience. Finally, the author participated in a visit to Toyota Motor Company on October 28, 2016, where the support that Toyota provided to Riken in 2007 was discussed in detail.

### *2.1. Overview of Riken and Its Products*

Riken Corporation started out as Rikagaku Kogyo, which was founded in 1927 to commercialize the output of the Institute of Physical and Chemical Research, a research laboratory of the national government. The Rikagaku Kogyo Group (a zaibatsu) was broken up in 1949 after the end of World War II into 11 independent companies, one of which was the company that would later change its name to Riken Corporation.

Riken opened its Kashiwazaki Plant in Niigata Prefecture in 1932 as a piston ring manufacturing facility that included equipment for casting metal. The company opened its Kumagaya Plant in 1939, which at the time was also a plant dedicated to the manufacture of piston rings. In the post-WWII period, Riken engaged in technical cooperation agreements with overseas companies in the 1950s and 1960s to improve its precision casting techniques and refine its piston ring technology. From its beginnings, Riken has intensively collaborated with its automotive customers and suppliers in Japan to perfect its product and production processes.

In 1983, Riken constructed a second plant in Kashiwazaki City, the Tsurugi Plant (about 1/3 the size of the Kashiwazaki Plant and located 5 km away), to specialize in the manufacture of steel piston rings. Riken's R&D facilities for piston rings are located at the Tsurugi Plant. The two plants together have buildings that cover approximately 102,000 sq. meters. In 2014, there were around 1,500 people (including non-regular personnel) employed by Riken at its two plants in Kashiwazaki City. In addition, 9 companies that are Riken affiliates and around 40 of its suppliers are located within the Kashiwazaki City limits.

On a consolidated basis, Riken employed approximately 4,000 people in Japan in 2014, with sales of 75 billion yen (approximately 715 million USD at the time), on which it earned current profit of 7.3 billion yen. Riken has long supplied around half of the piston rings used by Japanese automakers in Japan. The company sells to all Japanese and many overseas automakers. Riken also supplies piston rings for use in motorcycles, construction machinery, aircrafts, ships, and seal rings for transmission manufacturers.

Riken is best known as the largest developer and manufacturer of piston rings in Japan. Building on its position as the leading Japanese piston ring manufacturer, Riken opened its first overseas joint venture in Taiwan in 1968. International expansion was pursued by Riken opening joint ventures in Thailand (1974), Indonesia (1974), India (1986 and 2014), the US (1989), and China (1990). Riken opened its first fully owned overseas manufacturing subsidiary in China (Wuhan) in 2004. Its second fully owned subsidiary was opened in Mexico in 2012. Some of these overseas plants supply products other than piston rings.

In 2013, the average number of piston rings manufactured by Riken each month totaled 17 million in Japan and 23.5 million overseas. In addition to piston rings, Riken also develops and manufactures cast metal parts (e.g., steering knuckles, differential cases, pressure plates, camshafts, crankshaft sleeves) for industrial and automotive use, as well as precision components (e.g., vanes for compressors, valve lifters). Although Riken produces camshafts and castings for automotive suspension parts at its Kashiwazaki Plant, most of its domestic production of products other than piston and seal rings is done at its Kumagaya Plant. Riken's sales are dominated by its piston ring business and, in 2014, 83% of the company's sales were automotive related.

Piston rings play a major role in determining the durability of an engine. The core competence of piston ring manufacturers is steel and aluminum coating capabilities to create the best seal with the least amount of resistance. A better seal prevents oil from leaking into the piston chamber, which damages the engine and has a negative effect on fuel economy and exhaust emissions. On the other hand, a seal that is too tight will make the engine work harder than necessary to produce power, thereby also lowering fuel economy and potentially harming the durability of an engine. Improved coating of the rings is one way to overcome this inherent trade-off.

Over the years, the so-called black-box parts development of piston rings has evolved, with automakers increasingly asking for greater amounts of information on test results, characteristics of materials, and so on. The already severe requirements on piston-ring manufacturing—due to high levels of complexity caused by interdependencies between piston rings, pistons and cylinders—have multiplied further as differing specifications are needed for different fuel types, putting an ever heavier burden on piston ring manufacturers. When requested, Riken sends guest engineers to work inside the technical centers of some of its customers.

Riken has its own engine testing facility in Kashiwazaki City and employs many R&D personnel performing product and process design. Riken works closely with the automakers and piston and cylinder suppliers. In Japan, piston ring suppliers traditionally worked directly with the automakers as first-tier suppliers. Recently, the purchasing of some Japanese automakers has started to align itself more with the global standard, where the piston ring manufacturer will only work with the automaker as a second-tier supplier, that is, through a first-tier "system supplier". Japanese piston ring manufacturers tend to prefer to work directly with the automakers, so that they can receive information about the engine concept and its specifications from the engine designers and communicate closely with them.

When an all-new engine is developed, Riken works with the automaker directly (or through a system supplier) from the initial decision on the engine concept to the end of the development project. It is a process that generally takes around three years. The breakdown of this period is an initial intense preparation phase, core development work, followed by a long verification phase, including many endurance tests and presentations to the customer to get final approval for the piston rings to be manufactured on specific production lines, which creates the high asset specificity of this product. Changing production lines is only possible after the extensive verification process is fully repeated.

## 3. Riken's Pre-Disaster Preparations

After an earthquake that occurred in Niigata in 2004, Riken performed an extensive analysis of the earthquake resiliency of its buildings in Kashiwazaki City. Based on the results of this study, various fire-prevention measures were implemented and a plan was made to strengthen the building structures. Riken had finished the principal component of the construction plan, namely installing pillars and crossbeams in the center of the main building at the Kashiwazaki Plant, before the 2007 earthquake hit. Had it not been for these reinforcements, this building could very well have collapsed.

A comprehensive back-up system for the company's data systems was also implemented following the 2004 earthquake, as well as strengthening of the building housing the IT servers. As a result, Riken had up-to-date data as of the day before the 2007 earthquake. Moreover, after 2004, an emergency generator was also installed, which automatically turned on a newly installed emergency lighting and PA system when the 2007 earthquake hit.

Another way in which Riken responded to the 2004 earthquake was by writing a business continuity plan (BCP). Although the plan proved to be rather insufficient in various ways, it did help Riken quickly establish two situation control rooms, one at the Kashiwazaki Plant and one at its Tokyo headquarters, and make a fast start on checking the condition of all of its employees in the area. The BCP plan also contained a list of the cell phone numbers of the presidents of all the companies that were suppliers, customers, or other important partners of Riken's facilities in Kashiwazaki City.

## 4. Earthquake Damage and Recovery at Riken

A major earthquake off the Western coast of Niigata Prefecture, Japan, which occurred at 10:13 in the morning on July 16, 2007 and which registered 6.6 magnitude on the Richter scale, was soon followed by a 6.8 earthquake in the same area. Both of these quakes, but especially the latter, strongly shook Riken's facilities in Kashiwazaki City. It was a national holiday and few people were at the plant, with almost no lines operating at Riken or its affiliated companies in the city, which helps explain why there were no fatalities at Riken, although 41 people who worked for Riken or its affiliated companies did suffer earthquake-related injuries, 13 of whom required workers' compensation. Riken's piston ring manufacturing lines, casting lines, and camshaft lines were all severely damaged.

Riken's Kashiwazaki plants were the sole source of the piston rings used in many vehicles assembled by Japanese automakers. The severe disruption of Riken's production lines, coupled with the low inventories held by Japanese automakers, quickly forced vehicle assembly plants to stop production, which in turn led to the stoppage of many other auto parts suppliers in Japan. Newspaper, industry, and government sources report that, between July 19 and 23 all automakers in Japan had to stop production at least at some of their plants due to the disrupted supply of piston rings from Riken. Whitney et al. (2013) report that some have estimated the Japanese auto industry's losses from the earthquake at 100 billion yen (820 million USD at the time), with most of this related to delays in vehicle production due to the disruption at Riken. Establishing substitutive production for highly asset-specific parts, like piston rings, has a very long lead time, so on-the-spot recovery needed to be done as rapidly as possible.

All of the approximately 1,100 machines used by Riken to manufacture piston rings at its Kashiwazaki Plant were affected in some way by the earthquake: 65% were shifted off their base, 18% were titled, and 17% were knocked over completely. Riken also found that many of the plant's 5,000 dies, gauges, and measurement tools had fallen off their racks. Furthermore, 7.6% of work-in-progress inventory and 0.3% of finished goods inventory were damaged by the earthquake.

As for casting lines used to manufacture automotive suspension parts, one sand bin fell over and was damaged, and one had its supports broken. Three sand bucket elevators were damaged, as were dollies for transporting finished molds. The rack for holding finished molds also fell over, damaging 104 molds. For camshaft manufacturing, 98% of the approximately 120 machines were shifted off their base. Since it became immediately clear that there was significant damage at its Kashiwazaki facilities, the company sent as many personnel as possible to the affected sites from its other domestic plants (including affiliates) and Tokyo headquarters. Such personnel were sent to assist in the recovery efforts, including filling in for Kashiwazaki personnel who needed to take care of their own families and local communities that had been devastated by the earthquake.

Hundreds of relief personnel from Riken's customers (automakers) and other companies (e.g., equipment, parts and material suppliers) also came to assist in the recovery. The first groups began to arrive at Riken on July 17, the day immediately after the earthquake. At the peak, on July 23, when volume production was restarted, over 800 relief personnel from external stakeholders were at Riken's site supporting the recovery effort. They had to work around the clock to test and retest production lines to ensure pre-earthquake quality levels. Between July 17 and August 11, the cumulative number of relief personnel who participated in the recovery effort came to more than 7,900 people.

The recovery effort at Riken was greatly supported by the experience of automakers, notably Toyota Motor Corporation, which used expertise gained from past earthquake-induced disruptions at suppliers, such as after the Kobe earthquake in 1995, to identify what kind of help would be needed at the disrupted site and in what sequence. The companies that sent personnel to support Riken's recovery efforts set up an On-Site Countermeasures Headquarters (*genchi taisaku honbu*) at the Kashiwazaki Plant, where meetings were held three times a day, after which reports were sent back to each company with requests for additional relief personnel and equipment.

On the two days immediately following the earthquake, July 17 and 18, the first wave of relief personnel began to arrive from the automakers and other companies that sent recovery assistance teams. These first responders were small advance teams to assist in surveying and assessing the damage. The teams were voluntarily sent by companies that sought to support Riken, and Riken assigned each team an area of concern, based on the experience of the people who had been sent. Riken's personnel joined each of the teams to work with them and guide them around the damaged facility, and some Riken workers were assigned to liaise with each recovery assistance team. To facilitate everyone working smoothly together and clarify roles and responsibilities, each of the people involved in the recovery efforts displayed his name on his shirt and hat.

In Riken's haste to check on the condition of its own employees and on the damage inflicted by the earthquake on its facilities, the company did not contact its customers and suppliers until the evening of the day of the earthquake (which had struck in the morning). Riken (2007a, 2007b) clearly states that the company regrets being slow in making initial contact with its customers and suppliers.
Following the earthquake and in parallel with its efforts to check on the condition of its employees, managers were sent out in pairs to survey the damage inflicted on Riken's equipment and buildings. During this task, the managers had always to be careful to secure access to an escape route in case of a large aftershock. In fact, there was only one large aftershock following the first earthquake, and having no other major aftershocks contributed to the speedy recovery described in this paper.

In reporting damage, mangers were instructed to clearly define the basis on which they carried out their assessment. Their evaluations were double checked, and the results were used to begin work on a recovery timetable. The advance teams thoroughly assessed the damage, set the overall recovery policy, estimated the amount of work required to solve each identified problem, and what personnel would be needed. The advance teams also had to estimate the expected dates when the supply of water, natural gas, and electricity would be restored to the plant. Moreover, it was important to obtain timely information on the state of the surrounding roads and bridges, which would be needed to bring people, equipment, and materials in and out of the disrupted sites.

Information and assessments were used to make recovery plans that were reported back to each company that had sent recovery assistance teams. While these early reports and requests for additional personnel were being sent, in those areas that were unlikely to be severely affected by any secondary damage from aftershocks, some of the advanced teams also began to work on righting smaller equipment that had fallen over or was otherwise impacted by the earthquake.

The second wave of relief personnel who came after the advance teams were experts and operators of heavy machinery—including TIR rollers, bars, jacks, and chain blocks which are used for installing and moving large machines—who were tasked with tapping their daily experience to reset equipment and ensure that production bases were smooth and level. The third wave was relief personnel who possessed the skills and experience to fine-tune production machines to achieve the required level of precision, re-establish the flow of the work-in-progress through the production lines, and verify quality assurance processes.

In some cases, rather than restoring production lines exactly to their pre-earthquake state, opportunities were taken to improve their layout. Among its many words of appreciation for the recovery assistance teams, Riken (2007a) contains a quote from a production manager who says that the cooperation of personnel from external stakeholders helped improve the production lines beyond what they had been before the earthquake. Riken’s personnel and some of the external personnel on the recovery assistance teams were already quite familiar with each other and with the equipment in the plants, due to many years of experience working together. This familiarity helped them to make these improvements and quickly set up a timeline for the recovery effort.

While heavy equipment experts reset the machines and made them operational again, personnel from the recovery assistance teams and Riken set targets for reducing cycle times and raising the operating efficiency of the equipment, which helped increase the speed at which lost production could be recovered after manufacturing was restarted. Such discussions were generally held not in a meeting room but right at line side to speed up decision making.

Based on the initial assessment as to the expected date for restoring water supplies to the plant, arrangements were made to truck in water for use in trial production and the rapid ramping up of large volume production. In addition, a heavy-oil boiler was obtained as a temporary measure until natural gas supply was restored. Arrangements such as these were made by relief personnel who were specialists in production planning and administration. These specialists also coordinated recovery work on issues that crossed multiple buildings and areas. In parallel with these efforts, experts in logistics from both Riken and external companies worked on resolving issues related to moving parts in and out of Riken and its suppliers’ plants, as well as delivering finished goods to its customers’ plants.

### *4.1. Production Resumption Timeline and Organization*

By July 20, four days after the quake, all of the damaged and fallen equipment had been righted. On July 23, the seventh day after the quake, volume production on most piston ring lines was restarted, with some of Riken’s customers also reportedly restarting production on this same day using the first batches of piston rings that came off the restored lines. July 23 was also the day that marked the peak number of relief personnel, 800 people, at Riken. By July 24, all but two piston ring lines were running. However, only half of the production lines for cast automotive suspension parts could be restored by July 23. It took a full two weeks for production to be restored on the remaining piston ring lines and casting lines. Nevertheless, two weeks was still well ahead of Riken's initial estimate of more than one month. After resuming production, some lines operated on three shifts instead of the normal two, which in some cases continued until the end of September to make up for lost production.

For production to be resumed on the piston ring lines, 1,300 gauges had to be checked and restored. On July 20, three days before the target date to restart production, it became clear that it would not be possible to finish checking all of these gauges in time. So, Riken quickly decided to divide the gauges up and send them to be checked off-site by the companies that had sent personnel to help Riken recover and then to have the gauges sent back to Riken. In this way, the job was completed in time. Likewise, when it became clear that replacement shipments and repairs of damaged equipment used to measure material strength and ring circularity would not be ready in time, Riken asked the companies that had sent recovery assistance teams to lend it such measurement equipment.

Once additional relief personnel arrived to join and sometimes replace the advance teams, the size of the recovery assistance teams grew to between 10 and 20 people. During the recovery period, progress reports prepared by the recovery assistance teams were shared with Riken's On-Site Recovery Headquarters (Riken no genchi honbu) at two daily general meetings, one in the morning and one in the evening, that were attended by representatives from all companies involved in the recovery effort. These meetings were important vehicles for information sharing. Moreover, to create an atmosphere of fairness, Riken's president decided that the post-recovery production schedule would be the same as what had been scheduled as of one hour before the earthquake struck.

Although there were differences across the recovery assistance teams as to the level of experience with past disasters, there was more or less shared awareness of the need to have multi-skilled teams that could deal not only with the types of equipment and tools used at Riken but also with general issues related to maintenance, electrical supply, and infrastructure. Past experience had shown which tools and equipment would be needed first and how to get them delivered quickly to a disrupted plant. There was also accumulated knowledge about how to secure sufficient food, water, and accommodation for personnel who came to support Riken's recovery.

The recovery activities of Riken and its external stakeholders were not limited to supporting only Riken's production recovery but were also extended to supporting the recovery of its affiliated companies and the surrounding community. Riken delivered blankets, cushion mats, and privacy partitions to a nearby gymnasium that was being used as an emergency shelter for people who could not return to their damaged or destroyed homes.

Following the earthquake recovery, Riken compiled and released two report booklets (Riken, 2007a, 2007b). The first one (16 pages) was distributed to the public at the end of September and was directed primarily at the larger community in Kashiwazaki City and all of Japan. The second one (19 pages) was printed in December and was directed at the many companies and people who participated in the recovery operations at Riken.

### *4.2. Long-Term Measures Implemented After the Earthquake Recovery*

In the months following the 2007 earthquake and recovery, Riken announced that it planned to take three long-term measures. First would be the placement of more inventory closer to its customers in Japan. Second would be the establishment of another production site in Japan, through which production would be diversified as a precaution against another major disruption. Third would be an effort to pursue increased standardization of its products with other piston ring manufacturers. The announcements followed criticism in the press of Riken in particular and just-in-time (JIT) production in general when it is coupled with high concentration of production at a single site. However, while the first measure was implemented, the other two were not.

The first measure has entailed Riken placing a week's worth of inventory in four new warehouses, two near Nagoya and two near Tokyo. Riken stores this additional inventory at its own expense and says that it bears this additional burden alone as a continued extension of its appreciation to the automakers that supported its recovery effort. The period of one week was determined based on the 2007 recovery experience having taken one week, even in the face of the severe damage caused by the disaster.

The second long-term measure was reconsidered and, following this further analysis, ultimately rejected. Riken has not constructed any new piston ring production facilities in Japan after 2007. Thus, it is clear that the company has chosen fortification instead of diversification. Whitney et al. (2014) describe fortification as putting all your eggs in one basket and carefully protecting the basket. Riken introduced numerous measures to fortify its piston ring production site.

Riken strengthened the earthquake-resistance level of all of its buildings in Kashiwazaki City. It also accelerated the placement of guards on racks to prevent parts, materials, work-in-progress inventory, and finished goods inventory from falling. Prior to the 2007 earthquake, Riken had been somewhat reluctant to use anchor bolts on some of its production equipment, due to the difficulties that anchoring can create when machines need to be moved to make changes and improvements to the layout of production lines. However, seeing the extent to which equipment fell over in 2007—with the grave possibility of loss of life had the earthquake occurred at a time when more people were in the plant—pushed Riken to reconsider its stance. The company is now pursuing an aggressive policy toward anchoring all of its heavier production equipment.

With regard to the third measure, that is pursuing increased standardization of its products with other piston ring manufacturers, additional research is needed to probe this difficult and long-term issue (for more discussion of this topic see Chapter 2 of Fujimoto and Heller, 2017). Riken (2007b) does not address this third measure and lists the company's two key findings from the production recovery experience as: (1) making more robust production lines that are simpler and shorter, and (2) ensuring that the company can meet the target established after the 2007 earthquake to restart production after a major disaster within one week.

From Riken (2007a) and visits to the company, it is clear that one of the main areas the company focuses its disaster preparation is in finding ways to get all of its employees to put risk management in the forefront of their activities, so that hidden risks can be made visible and managed. It can reasonably be expected that by doing so, Riken will be able to achieve its first priority, namely, to protect human life, as well as fulfill its responsibility as a supplier to keep its supply of parts flowing. A major production disruption at a supplier will not only stop its customers' production lines but also the lines of other suppliers that in JIT production cannot deliver their parts to their customers either, when one supplier's supply is interrupted. In this way, Riken's ongoing commitment to JIT production is a commitment to continuing to work closely with its customers and suppliers to improve disaster readiness.

## 5. Discussion

The Riken case shows that, when faced with a severe production disruption caused by a major disaster, such as an earthquake, timely on-the-spot recovery can be greatly assisted by close cooperation between the personnel of the disrupted site and recovery assistance teams sent by customers and suppliers. Having access to such support is especially necessary when plants supply products that are manufactured using highly asset-specific resources that cannot easily be substituted and there are low inventories of finished goods in the supply chain.

However, even if external stakeholders, such as customers and suppliers, have the motivation and ability to send relief personnel to support the recovery of a disrupted site, the site (and firm) has to be willing to accept, even embrace, such offers of help. This willingness will depend on the level of trust between the disrupted site and its external stakeholders. A firm must have a high degree of confidence that relief personnel from external stakeholders will not use any knowledge to which they might gain access during recovery activities to take advantage of the disrupted firm. Such knowledge may include production methods, equipment modifications, information on materials and ingredients, and other forms of valuable information.

Drawing on Sako (1991), Manabe (2002) divides trust into two categories, basic and relational trust. Having basic trust, which can be thought of as a form of arms-length trust, means that you are confident that the other side of a contract both intends and is able to keep the terms of the contract. Basic trust is a fully rational basis for entering into a contract in the first place. In contrast, relational trust can be the sometimes irrational willingness to go beyond what is contractually required when faced with extenuating circumstances, such as a sudden disaster.

Research has shown how the existence of high levels of trust and cooperation between companies can positively contribute to the overall competitiveness of a supply chain (Asanuma 1989, Nishiguchi 1994, Dyer & Nobeoka 2000, Fujimoto 2001, Takeishi 2001, MacDuffie & Helper 2005). Companies can build relational trust, both between OEMs and suppliers and between suppliers, by focusing on joint problem solving in product development and productive operations (Sako 1996, Manabe 2002, Kato 2016).

One way in which companies increase the level of cooperation in their supply chains is by implementing just-in-time (JIT) production. In 1984, a Toyota manager, Michikazu Tanaka, described the essence of JIT as not only reducing inventory costs but also the fact that "JIT reveals production problems and triggers Kaizen (continuous improvement)… (and furthermore) JIT keeps on forcing workers to face production problems one after another, the people finally start to see everything as a potential source of cost or productivity problems, and then seek problems actively" (Fujimoto, 1999, p. 271). As people working in JIT plants seek, find, and solve problems, their problem-solving ability gets better. Since JIT is by its nature about moving parts between work stations, work lines and plants, it is inherently cooperative and therefore nurtures the ability of people to work together to solve problems that cross work boundaries.

In a disaster-induced severe production disruption, problems do not need to be sought for—they are everywhere. During on-the-spot recovery, the vast number of overlapping problems greatly exceeds that which is encountered in the daily running of JIT production. However, many of the actual problems themselves and the pressing need to quickly restore production flows are fundamentally the same as disruptions that occurs in daily JIT operations, which helps explain how and why the JIT skill sets honed by Riken and its external stakeholders contributed to the rapid on-the-spot recovery that was achieved in 2007.

The Riken case even revealed a silver lining to the severe disruption, which were the production improvements that the recovery assistance teams implemented during their efforts. Kaizen thinking and the high operational expertise of the relief personnel allowed them to make changes to manufacturing line layouts that improved productivity at Riken beyond what it had been prior to the earthquake.

In closing, the first key finding from the Riken case is that companies with production facilities in earthquake-prone areas should check and, where necessary, strengthen the disaster-worthiness of their buildings, including fire prevention measures. Heavy production equipment should be secured with anchor bolts and measures taken to prevent tools and inventory from falling off storage racks. General emergency preparations are also needed, such as the installation of auxiliary power sources, food and water supplies, and planning where and how to supply temporary accommodation for relief personnel brought in to help with plant recovery and the restoration of local lifelines. Consideration must also be given and contingency plans made to accommodate the difficult personal situations potentially faced by workers and managers at the disrupted plant, who may have to deal with injuries or deaths of people close to them and damage to their own homes or those of neighbors and relatives.

The second key finding is that companies in a supply chain that have built up relational trust through sustained mutual investments of time and effort into cooperative activities can leverage this trust to speed up on-the-spot recovery efforts through the sending and receiving of recovery assistance teams. In this sense, trust building in the ways required for JIT production not only contributes to increased supply chain competitiveness but may also be the most important disaster preparation that a company can undertake.

Returning to the research question posed earlier in the paper, the Riken case suggests two important characteristics that facilitate the effective management of on-the-spot recovery when a disaster causes damage that goes beyond the ability of the disrupted firm to recover on its own. First is the existence of operational excellence and production personnel at the disrupted site with high skill sets in cooperative problem solving. Second is the existence of relational trust between a company and its external stakeholders that can be leveraged to speed up the recovery effort. Companies should recognize that continually making efforts to build operational excellence and trust in their supply chains can pay off in times of crisis.

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