Framework for Developing a Knowledge Warehouse Towards a Resilient Semiconductor Assembly and Testing Firm

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ABSTRACT Resilience emphasizes the recovery capability of a firm after an event of disruption. This paper proposes a framework in constructing a knowledge warehouse (KW) to increase a semiconductor assembly and testing firm’s resilience by using a backcasting approach, which consists of four steps to form the development cycles. In each cycle, the goal for moving towards resilience is set up. The second step is to identify the baseline problems. Several potential paths to reach the goal from the baseline are then analyzed. Finally, a proper path supporting the performance of specific activities (plan) is selected and further added to the KW. Therefore, any possible conflict caused from bringing in new knowledge to the existing KW should be examined and resolved. The KW is augmented through cycles. Two case studies (Earthquake and typhoon disruptions) are used to demonstrate the applicability of the proposed framework. Furthermore, discussions also refer to how Nissan and Renesas responded to a 9.0 earthquake in 2011 and to a world-class major provider of semiconductor assembly and testing services in developing its KW. At the end, several recommendations have been made for firms to prepare for resilience. Some related future research topics are also proposed.

INDEX TERMS Supply chain resilience, semiconductor, knowledge warehouse, backcasting, case study.

I. INTRODUCTION

Firms nowadays are experiencing fast moving paces in their business environments. Strong competition, complex supply chain networks, unpredicted disruptions, and natural disasters with serious damages force firms to focus on their risk management and extend this focus to the entire supply chain. In the area of supply chain risk management, supply chain resilience (SCRES) is a crucial topic that is attracting more and more attention [1-8].

SCRES is regarded as one of the vital attributes that supply chains need to develop to efficiently manage disruption. The concept of SCRES is believed to outweigh other traditional concepts in supply chain risk management in terms of disruption identification, focus, coverage, and ability of recovery and even growth [9]. In other words, in the event of disruption, supply chains need to incorporate their knowledge and awareness about the disruption by advance preparation for the possible disruption, effectively responding, and having sufficient abilities to recover to their original status or even to develop a better status after the disruption. This is the core essence of SCRES [10].

Of high technology industries, semiconductor industry is unique with characteristics of capital intensiveness, tremendous volume of facilities, complex supply chain networks, fast-changing technologies, commitment to capacity, and just-in-time (JIT) delivery [11-13]. All activities of a supply chain in semiconductor with these special characteristics have an inherent risk. These characteristics have made semiconductor firms to be aware that supply chain disruptive events can cause negative operational and financial impacts. Supply chain disruptive events in semiconductor can derive from various sources, including external antecedents (i.e., earthquake, typhoon, or tsunami)
or internal antecedents (i.e., chemical incompatibility or fire explosion).

Two supply chain disruptive events are described in the following. In 2007, a boiler of a Taiwanese semiconductor assembly and testing firm was overheating. The extended burning reached to production buildings and damaged multiple lines and equipment. It took two years to restore the affected lines and return to production. On March 11, 2011, a 9.0-magnitude earthquake and tsunami hit off the east coast of Tohoku, Japan. Facilities of Renesas Electronics at Naka were severely damaged. Renesas supplied semiconductor components worldwide including 70% of chips used by Nissan Motor [14]. Naka was a critical link with Nissan and other automakers’ supply chains. Although Naka’s production lines gradually restored since early June in 2011, Renesas reported an operating loss of 19.1 billion yen and net income loss of 33.2 billion yen [15].

As the possibilities of supply chain risks increase, the need increases for semiconductor firms to design and develop a resilient system that supports them to sufficiently manage the possible disruptions. These include preparing for the disruptive events, providing effective responses, and thus continuing their operation as planned. A question is therefore raised as follows and to be discussed in this paper.

“Is there a framework that semiconductor firms can follow to actively prepare their resilient system to manage the possible disruption should it occur, recover from the disruption, continue their operations at their full capacity, and even grow?”

The objective of this paper is to propose a framework for developing a knowledge warehouse (KW) to increase a semiconductor assembly and testing firm’s resilience. The SCRES concept and characteristics and vulnerabilities of the semiconductor industry will be firstly explored. The proposed framework includes a backcasting approach and stepwise flow to construct a KW. This study investigates two case studies (Earthquake and typhoon disruptions) to demonstrate the applicability of the proposed framework. Knowledge in the KW represents strategy, as a series of action plans and precautions. It can also be a case of failure to avoid repeating the same mistakes. The KW supports semiconductor firms to be resilient. For example, through drills, the KW is continuously augmented, so semiconductor firms are able to improve their resilient capabilities. However, the consistency from bringing in new knowledge to the existing KW should be ensured.

The remainder of this paper is organized as follows. Section II provides an overview of related research on the concept of SCRES, SCRES capabilities, and KW frameworks. Section III addresses a backcasting approach and the proposed framework. Section IV discusses the semiconductor industry and a case company. Two practical cases of earthquake and typhoon are addressed in Section V to illustrate how to apply the proposed framework for the development of a knowledge based resilient warehouse. Section VI summarizes this research and points out future directions.

II. LITERATURE REVIEW

A. SCRES

In the presence of various uncertainties, supply chain risk management (SCRM) plays a vital role in the effective operation of a business [16]. SCRM concerns an implementation strategy to manage risks along the continuous risk evaluation, aim to lessen vulnerability and assure continuity [6, 16, 17]. Risk management involves activities of detection, measurement, and assessment of potential supply chain disruptive events originated from either inside or outside the supply chain [18]. Since the risks and possible disruptions are frequent with severe damages, firms need a proactive approach to face them [7, 16]. Specifically, firms not only need to be aware of the risks of disruption and mitigate disruptive damages, but also need to shift their special attention to how to recover from the disruptions, continue their operations, and even keep their growth. Such situation poses a new challenge but an opportunity for scholars and practitioners to approach an innovative concept of SCRES [5, 19-21].

As indicated in references of Walker and Salt [22] and Hosseini et al. [23], the concept of resilience is wide-ranging, and originates from multiple domains of engineering [24], ecology [25], psychology [26], and disaster relief [27]. A number of arguments acquired from these fields are used to define SCRES. Grötsch et al. [28] described SCRM’s objective as to construct, maintain, and develop a resilient supply chain. On the other hand, not every possible risks could be avoided and then SCRES relates to the capabilities of preparing for unpredicted disruptive events, responding and recovering from the events even more quickly than the competitors [2-4, 9, 10, 29, 30]. Adobor and McMullen [31] further claim an evolutionary resilience as a measurement of how firms move or grow to new and better state after disruptions.

In terms of the chronologic order of disruption happening, the SCRES can be addressed in three critical time phases of pre-disruption, during-disruption and post-disruption [32]. The subjects of pre-disruption include preparation, resistance, avoidance, and alertness. Subjects of response, coping with changes, and adaptability are used to characterize the phase of during-disruption. Furthermore, subjects of recovery, survival, restoration, and return are applied for the phase of post-disruption. Initially, the focus of SCRES was on the last two phases, i.e., the during-disruption phase and the post-disruption phase [29, 30, 32, 33]. Over the time periods, the focus of SCRES shifted to include elements of resilience-preparation and growth [1, 21, 34-36]. In other words, all three critical phases should be covered, and well-integrated and coordinated.
B. SCRES CAPABILITIES

Referring to [9, 34, 35], a resilient firm should equip five capabilities to effectively cope with disruptions. They are the ability to anticipate, ability to adapt, ability to respond, ability to recover, and the ability to learn. The ability to anticipate is a proactive capability and belongs in the pre-disruption time phase. With this capability, a firm should be alert and able to develop a proactive plan in advance. The ability of adapt and ability to respond are in the during-disruption time phase. They are capabilities to manage critical resources to cope with unexpected disturbance and to react to supply chain disruptions to lessen their impacts. The ability to recover and ability to learn are capabilities of the post-disruption time phase. Especially the ability to learn, its core is the knowledge management (KM) and is the most important capability. This capability requires firms to understand what happened and improve future performance based on the experience. This capability also assists firms’ sustainable growth. Abovementioned can be illustrated as in Figure 1, which comes from [37] and is a variant figure from [9] but more comprehensive, to emphasize the knowledge management diffusion across all three phases. Knowledge can be used as a basis for preparation. Knowledge can also be used as a guide and action plan during the disruption. After the disruption, knowledge is accumulated to strengthen the content of the KW.

Other messages revealed from this figure are the three types of resilience and eleven key elements. Adobor and McMullen [31] claimed that engineering resilience, ecological resilience, and evolutionary resilience are three types of resilience across phases of pre-disruptions, during-disruption and post-disruption (or said, readiness, response, recovery, growth and renewal). The eleven key elements (i.e., supply chain network design, human resource (HR) management, collaboration, SCRM culture, flexibility, visibility, information technology (IT) capability, robustness, agility, redundancy, and financial strength), recognized by most researchers support SCRES capabilities. In other words, these elements will affect the required efforts and reachable level in developing a KW towards resilience. The detailed discussion can be found in [37].

Holling [25] defined the engineering resilience as the ability of a system to return to an equilibrium or steady state after a disturbance. The level of resistance to disturbance and the speed that the system returns to equilibrium is the measurement of engineering resilience. Contingency planning is an effective tool for engineering resilience that demands risk analysis and determination of the probability of disruption’s impact, and the development of response alternatives [31]. A key aspect of contingency planning is the development of the capacity to develop an early warning system which can forecast and monitor possible disruptions to the supply chain before they occur [32, 38]. Business continuity planning also is one tool that firms can choose for managing supply risks [39]. For example, Nissan’s business continuity plan (BCP) prioritizes critical issues in order, where physical safety of employees has the most concerning than protection of facilities and restoration of operations in timely manner do [40]. To summarize, engineering resilience can allow firms to recover quickly from a disruption. It represents for the efficiency [1, 19, 21, 31, 36].

Different from engineering resilience, ecological resilience is defined by how much disturbance the system can take while maintaining within some crucial thresholds but not how long it takes a system to bounce back after a shock. Therefore, ecological resilience is about adaptation that may include the ability of absorbing and withstanding. In the end, ecological resilience promotes overall system response as it enables firms to adapt to shocks [3, 21, 31].

When disruptive events take place with long-term impact, the system not only needs the ability of adaptation but also the capability of transformation to the new state. Evolutionary resilience has been defined as the ability to change, adapt, and transform in response to external and/or internal disaster. Evolutionary is measured by how firms move or grow to new and better state after disruptions [5, 20, 31, 36]. Therefore, the capabilities to three types of SCRES are essential for companies.

C. KW FRAMEWORKS

Researchers have developed various KW frameworks to increase and retrieve knowledge for different industrial applications in order to increase the successful chance on implementation of a new project. Alhawari et al. [41] studied the risk management with KM problems and developed a conceptual KW framework (knowledge-based risk management, KBRM) based on identification of the essential elements needed for innovative information technology (IT) projects. Their knowledge-based risk repositories are composed of knowledge-based risk capture, discovery, sharing, evaluation, and education. Based on the proposed framework, decision makers can improve the risk response planning process, including risk identification, analysis, and execution, for IT projects. Shan et al. [42] developed a KW framework for the emergency response decision support system (ERDSS), which contained 10 functional modules: emergency service helpdesk, command and coordination center, emergency plan management, emergency relief supplies management, emergency finance budget management, emergency organization and activity management, emergency knowledge warehouse, emergency warning management, emergency alarm management, and problem analysis and management. They illustrated the conceptual architecture of each functional module and conducted a case study (Shanghai emergency management decision support system, SH-EMDSS) to validate the proposed framework.

Mourtzis and Doukas [43] developed a KW framework for advanced manufacturing in the mould making industry. The core element of their framework was a knowledge repository
to import, use, and update the data model schema. They used IDEF0 to illustrate the proposed framework based on the case study. Through using apps to communicate with the case company’s web platform, design engineers can assess the existing knowledge in the KW to design a better mould to satisfy customers’ needs. Baydoun and El-Den [44] studied the existing software service supply chain (SSSC) frameworks and analyzed how to integrate knowledge management concepts based on the SSSC lessons learned into the existing frameworks. They analyzed Done’s framework for service supply chain, Yi Jiabin’s framework for manufacturing supply chain, Mehta’s framework for global software supply chain. Baydoun and El-Den [44] then proposed a knowledge-based framework for the SSSC, including three processes: project administration, internal development, and external implementation. Based on the testing analysis of the identification of knowledge source, KM process, knowledge retention, and knowledge retrieval, they demonstrated the applicability of the proposed framework. Huang et al. [45] developed an information integrated framework, which included three systems of data management, knowledge management, and model management, for urban railway transit (URT) public-private partnership (PPP) projects based on the data management system and the KW system. They introduced five stages of the URT PPP information integration framework and integrated the risk concept into the URT PPP project risk information integrated framework. Then, they combined the reward mechanism with the proposed integrated framework. Therefore, the proposed framework can help managers make decisions on analyzing project risks, project revenue, and project expenditure through the established KW. Overall, the above studies show that a good KW framework can help decision makers make better decisions through using existing knowledge.

D. SUMMARY AND MOTIVATION

Based on the literature review, a good KW framework can help decision makers reuse existing knowledge to improve performance on the company’s goals. For the SCRES, different types of knowledge in a KW can be well managed to reach all three types of resilience. Simply speaking, good management of knowledge helps decrease supply chain vulnerabilities and positively support SCRES. While knowledge management exists across three time phases, more effort should be placed on proactive planning and reactive learning, so that less chaos will be caused by disruptions. Therefore, this study develops a KW framework for a semiconductor assembly and testing firm’s resilience and uses two case studies to verify the applicability of the proposed framework. The details of the proposed framework are introduced in the next section.

III. PROPOSED FRAMEWORK

Of the framework, backcasting is the core. It will be introduced first. The proposed framework is presented in a stepwise flow. Steps to reach resilience are also briefly explained in this section. Details of the application of the framework will be further illustrated by a case study in Section V.

A. BACKCASTING

Backcasting is an approach that begins with defining a desirable future and then works backwards to identify actions that will connect the specified future to the present [46]. In other words, backcasting is a process of beginning with the end (i.e., the goal) in mind [47]. Such characteristics motivate this research to employ backcasting approach as a core of the framework in constructing a KW for semiconductor assembly and testing firms.

Backcasting was initially introduced by Lovins in the 1970s [48] and later applied and refined in the field of sustainable development by The Natural Step in a collaboration with scientists [47]. Although backcasting was first applied in electricity supply and demand, this method has further employed in various disciplines including human resource management, sustainability [49], green product development [47], and the resilient energy system [50].

The backcasting approach consists of four steps named ABCD [51]. Step A is to set up the awareness and vision (goal) for future status. It involves the alignment of a firm’s understanding of resilience and awareness of the contextual situation for the firm, building a common language around resilience, and creating a target of what the firm will achieve in a resilient future. During the visioning process, the firm is encouraged to set ambitious goals that may require radical changes in its operations.

Step B is to identify the baseline problems and characteristics of the current state. It consists of conducting a resilience gap analysis of the firm. In this step, possible disruptions or rising problems to reach the predefined vision (goal) should be identified and are further aligned with firm’s resource, operation capabilities, or existing process. The alignment is critical to ensure an action plan to be successfully developed in Step C and capable implemented by the firm. Because the resilience issues may be across the entire supply chain, the suggested analyses can include the impacts on products, energy, capital power, and human resources within a firm or over all partners. Other critical components ought to be concerned are the social context and firm’s culture, which show additional dimensions to the analysis and are essential for understanding how necessary changes can be positively incorporated into the system. Especially for a multi-national company, a firm’s culture will influence the success of transferring resilience experiences from another firm. Step C is to construct a strategy and
Types

- Engineering Resilience (Efficiency)
- Ecological Resilience (Adaptation)
- Evolutionary Resilience (Growth and renewal)

Phases

- Pre-disruption: Readiness
- During-disruption: Response
- Post-disruption: Recovery

Abilities

- Proactive Capability
- Concurrent Capability
- Reactive Capability
- Combination of Reactive and Proactive Capabilities

Key Elements

- Supply chain network design
- HR management
- Collaboration
- SCRM culture
- Flexibility
- Visibility
- IT capability
- Robustness
- Agility
- Financial Strength

Results

- Competitive advantage

FIGURE 1. A COMPREHENSIVE VIEW OF SCRES.

Four Circumstances

1. Initiate a New Cycle
2. Apply a Backcasting Approach

Strategies/ Guide

3. Step A: Setup a Goal

Analytical Tools

4. Step B: Identify the Baseline

Facilitator Team

5. Step C: Generate Alternatives

Knowledge Warehouse

6. Step D: Conclude the Path to Goal

If necessary, a recursive loop is executed to redefine A or reprocess (B and) C.

FIGURE 2. PROPOSED FRAMEWORK AND STEPWISE FLOW TO ENHANCE RESILIENCE.
solutions for moving towards resilience, referring to the gap being identified in Step B. Strategies with creative solutions are designed according to looking backwards from a vision that has been set. Opportunities and potential activities are defined and prioritized to move the firm toward a desired level of resilience. Meanwhile, flexibility and economic returns are also considered. Finally, Step D refers to advising and supporting the performance of specific activities (plan) by offering suitable training, techniques, and tools for implementation.

B. FRAMEWORK AND PROPOSED FLOW

As shown in Figure 2, the framework of proposed flow has six steps on the backbone, which interact with a KW and analytical tools to support required analyses and decision making. The backcasting approach consists of Steps A, B, C, and D. All knowledge of a KW must have been collated and verified. The resilient knowledge represents activity planning, action or implementation plans, alignment of various resources, manpower coordination, disaster prevention standard operation procedures (SOPs), and SOPs in response to during and after disasters. Each disaster situation has its own SOP. Knowledge also contains strategies that companies can refer to.

Knowledge comes from experience and learning, including academic and practical learning [52]. Knowledge can be accumulated through continual training, learning, and evolving. Basically, there are four types of circumstances that trigger a cycle of learning to accumulate experience and enrich knowledge. However, the construction of the most initial and basic KW could begin at the learning from leading international firms (e.g., leading semiconductor firms in Japan).

Figure 3 demonstrates how the development of a KW is evoked via an IDEF0 presentation [53]. Firstly, the KW can be augmented through drills. Firms simulate various disrupting situations to train the current KW and to ensure any necessary adjustments being correctly contained within.

The second way to update the KW is through the post-review of a disruption that firms have faced. The occurrence of a disruption offers firms an opportunity to re-examine the capability of the current KW. An improvement of the KW is therefore conducted. Because of the feeling of presence, these practical experiences may even result in a recommendation to raise up a firm’s awareness, such as, to reduce the recovery period, or to reset the resilience capability at a higher level.

Third, the updating run (cycle) of a KW can be evoked by a recent happening natural disaster or disruption in the world. Once a firm feels the value of this disaster or disruption, a new drill starts and the current KW is examined and enhanced. The fourth circumstance to augment the KW is led by the innovation of any new technology to increase the ability to adapt, respond, or recovery from a disruption.

In summary, through pilot runs, practical drills, and reviews, knowledge data are collected. A KW is then required and continuously verified, developed, and augmented. In each cycle, the backcasting helps find the best solution for firms coincident with particular vision (or goal) and existing baseline. To guarantee the success of a KW, the top management involvement is very important. Firms need to form a team (called facilitator team) including members from the top management and functional divisions to guide the KW development following a firm’s established strategy and to ensure KW’s quality and capability. The KW’s continuous improvement process consists of a series of monthly facilitator team’s meetings finishing with strategic decisions and implementation plans to react to proposed disruptions. In a meeting, facilitator team may identify benchmarking competitors, collect and analyze benchmarking information, and take actions to match or exceed the competitors. For example, Nissan’s no fatality and recovery from a magnitude 9.0 earthquake disaster within two months make Nissan being considered as a benchmark competitor [40]. Another example of decision is setting up a high level of resilience to reduce disruption and to capture more market share. In the globalization era, firms have factories around the world. Culture becomes another factor to adjust an existing KW when an overseas factory is opened. For example, culture difference in language, mindset, value, or operation environment might cause conflicts and misinterpretation.

Given a goal in Step A, as shown in Figure 2, Steps B-D essentially can be formed as a recursive loop. In particular, when a desired goal affects a wide range of functional divisions and affairs, the development of a comprehensive resilience system will take a gradual approach. The analysis process of one loop may obtain partial outcomes (or recovery plans). In other words, for simplicity of execution, one analytical loop may focus on one part of disruption first and another loop is started for another part of disruption. Therefore, the augmented KW will be continuously evaluated and revised. Such evaluation may verify the vision in Step A and the baseline, solutions, and actions in the Steps B, C, and D, respectively. At each step, knowledge is involved and accumulated. Consistency checking between the new knowledge and existing KW is also necessary. Iterative process enables the continuous improvement of the level of resilience that supports firms to enhance their resilience capabilities to manage various types of disruptions, different failures, and changes in the operating environment.

On the other hand, there exists a situation where the occurrence of one disruption may follow the other disruption’s occurrence. Example was the earthquake and tsunami followed by a nuclear crisis in Japan. Therefore, based on abovementioned cases, the inner loop among Steps A, B, C, and D of the framework in Figure 2 can be expanded shown as in Figure 4. To assist the illustration, let earthquake be the first disruption under consideration and...
tsunami be the second disruption. In Figure 4, A1 is denoted as for the Step A in dealing with earthquake alone. B1, C1, and D1 are corresponding steps associated with A1. The knowledge based resilient warehouse KW1 supports the development process of this cycle. KW1 is updated after the execution of the cycle. When the tsunami is further involved together, the step in defining a new vision is denoted by A1+2. Corresponding notations, B1+2, C1+2, and D1+2, are used to replace B1, C1, and D1, respectively. The vision in A1+2 can be, for example, that firms should be recovered from both earthquake and tsunami within a certain time period. The baseline under the study in the earthquake case (B1) shall be differed from B1+2, so are C1 vs. C1+2 and D1 vs. D1+2.

KW1 is referred in the analysis process of A1, B1, C1, and D1. On the other hand, KW1+2 is for the analysis of A1+2, B1+2, C1+2, and D1+2. However, KW1 is not necessary a subset of KW1+2. KW1 will not be removed due to the appearance of KW1+2, because KW1 corresponds to the occurrence of earthquake alone. In forming the KW1+2, it is possible to remove a portion from KW1 and add a new portion to. This is because any conflict of pre-applied knowledge should be resolved or removed when firms build up their KWs from bringing in disruptions one after another. Example is a different priority of resource allocation defined in the KW. Another example is the demand for advanced communication methods leading to investment in high-level equipment. The changes from KW1 to KW1+2 can also be applied between two similar cases (or failures). This is to find SOPs for a similar case from the existing KW1, adjust them, and apply them to the new case (KW1+2).

IV. INDUSTRY AND COMPANY BACKGROUND

The semiconductor assembly and testing industry is the target of this paper. The selected case company in discussion is a representative in this sector and its KW can even serve as a benchmark. Before detailed illustration on how a KW for disasters can be developed at the case company, characteristics of semiconductor industry and the background of the case company itself are discussed in advance.

A. CHARACTERISTICS OF THE SEMICONDUCTOR INDUSTRY

Semiconductor industry has a worldwide distributed supply chain. It is a multi-tier and highly specialized supply chain network [12]. Such a complex supply chain indicates a strong interdependence among each tier of the network. Therefore, any disruption in one tier may cause a “domino effect” for the disruption of the whole supply chain.

Semiconductor is one leading industry in Taiwan. According to Taiwan Semiconductor Industry Association (TSIA) report, Taiwan accounts for approximately 73.2% of IC foundry revenue all over the world, 55.84% of worldwide assembly and testing revenue, and 18% of worldwide design revenue [54]. Therefore, it does matter to retain the vitality of semiconductor industry in Taiwan.

Semiconductor firms are capital intensive. It means that capacity utilization significantly affects the capital effectiveness and profitability of semiconductor firms [55-57]. The capital intensiveness is reasoned by the tremendous investment on complex processes of research and development (R&D) with rising costs required, the necessity of economy of scale, and the costs to upgrading plants or building new ones [58]. Economy of scale is critical to semiconductor firms to amortize the high fixed-costs, reduce unit price, and increase competitive advantage. Particularly, the economy of scale should guarantee promised capacity to customers’ requirements.

Another characteristic of semiconductor industry is the just-in-time (JIT) approach, which has been applied in either warehouse replenishment [11] or production process. The original JIT concept concerns eliminating excess inventory that makes problems immediately evident. In other words, JIT emphasizes complete elimination of waste and in particular waste due to delay.

In semiconductor, JIT especially refers to careful production scheduling and on-time delivery. Assembly and testing firms are requested to deliver to the designated warehouse on time according to the JIT model. In other words, this warehouse serves as a buffer and manages the inventory. When the inventory is lower than a pre-set level, it requests assembly and testing firms to replenish based on JIT. This warehouse actually has the role as a hub, collects the finished products received from the assembly and testing firms, and then ships according to customer orders. Usually a customer order contains products from multiple firms. All the products must be ready before the shipment. In this case, fulfilling the JIT requirement becomes more important.

Regarding the production process at a semiconductor assembly and testing firm, the packaging process is firstly performed on a general-purpose equipment. Then, items are processed at the more specific and expensive testing equipment. Through both packaging and testing processes, finished products are ready to customers. To be tested, items are varied and dependent on customer needs. The load boards in assistance of the testing are usually provided by customers. So, the testing requirements are customized. Because of a high cost, firms fully utilize a testing equipment’s capacity and may lead to a bottleneck. No reserved capacity will be possible. In fact, beside trusted technology, semiconductor firms’ pursuit is to be a trusted capacity provider. Continuity of production and delivery does matter. Third-party logistics (e.g., UPS or FedEx) follows the hub’s orders and pre-determines a pickup timetable. Firms schedule the JIT production for a variety of product types accordingly. All these mentions show how crucial the JIT is to a semiconductor firm. When facing disruptions, if firms cannot promptly recover from disruptions, the supply chains they support would be broken off either.

Overall, these characteristics require semiconductor firms to ensure their continuity. They need to have a proactive plan
Figure 3. An IDEF0 representation in developing a KW.

FIGURE 4. AN EXPANDED SCHEMA OF LOOP ABCD.
to prepare for possible failures, mitigate the damages and quickly recover from the disruption to continue their operations. This is the essence of SCRES. However, to achieve business continuity, cost is an important consideration. The recovery speed back to normal from disruption is also related to cost. Depending on the firm’s recognition of the business continuity, the trade-off on corresponding cost will be different.

B. CASE COMPANY

The case company is a provider of semiconductor assembly and testing services. It is a major service provider with 19 percent of the world’s market share. Over 90 percent of the world’s electronics companies have been served by the case company. Its assembly processes include wire bonding, forming, trimming, and molding. It also offers packaging without molding services of fan-out wafer-level packaging (FO-WLP), wafer-level chip-scale packaging (WL-CSP), flip chip, as well as, 2.5D and 3D packaging.

Prior to the 1980s, the integrated design and manufacture (IDM) was a popular model in the semiconductor industry. Company (e.g., Intel) owned and operated its facilities from design to manufacture chips. In 1994, the Fabless Semiconductor Association (FSA) was established to promote the fabless business model. In 2017, Qualcomm, Broadcom, and Nvidia were the top three leaders for fabless companies. Since this fabless manufacturing, which concerns the design and sales of hardware devices only, became the trend, many IDM companies had completely transferred their equipment, special molds for assembly, and production capacity to the case company. Some customers may even not have any other outsourcing besides the case company. Therefore, one-stop shopping is a focused service to customers provided by the case company. Under this service, the case company cannot accept the chain breakage of any product especially caused by lack of materials.

Assembly capacity is usually greater than the testing capacity. The testing equipment is always a bottleneck and should be carefully and strictly scheduled to match with customer’s (or say, the third-party logistics) delivery dates. So, any unnecessary idle time because of a bad schedule arrangement or awaiting a load board on testing equipment may lead to an uncompensated capacity loss. Furthermore, there are many customers for assembly services. Each product has its own bill of materials (BOM), and the production quantity and delivery time will change significantly due to the changes of customer's market demand. To cope with these issues, the case company must compress the replenishment lead time of materials. The transportation of raw materials to factory becomes a challenge. No interruption should be allowed. In conclusion, winning customer’s confidence through right time, right product, and right amount supply is one competitive advantage of the case company. This requirement for business continuity is also the norm for many large multinational corporations, such as Nissan and Renesas of Japan.

V. KW DEVELOPMENT: A CASE STUDY

Natural disasters are severe threats to the high-tech industry. As indicated, in 2011, the compound natural disaster of earthquake and tsunami in Japan posed serious effects on semiconductor firms [59]. Tokyo Electron’s wafer fab in Fukushima, which was responsible for 20% of the world’s production of 300mm wafers, had been closed since the earthquake hit. As mentioned in [60], the aftershock activities of this earthquake were vigorous. There were five aftershocks at a level of 7-magnitude or higher and eighty-two aftershocks at a level of 6-magnitude between March 11 and June 11. Both Renesas and Tokyo Electron took roughly two to three months to resume normal operations. Another example was the Miho fab of Texas Instruments, in Japan. The earthquake caused damage to Miho fabrication's infrastructure systems for delivering chemicals, gases, water, and air. Besides these, semiconductor firms also suffered from issues of getting raw materials, employee absence, electricity supply interruptions, plus transportation and delivery.

A. TYPES OF DISRUPTION UNDER STUDY

Taiwan is among the area significantly affected by seismicity and frequently experiencing earthquakes. Between year 1901 and year 2000 there were 91 major earthquakes in Taiwan, 48 of them resulting in loss of life. Specially, in 1999, the Jiji earthquake at a Richter magnitude scale of 7.3 killed 2,415 people and led to a US$ 10 billion worth of damage [61].

Typhoon is another common risky natural disaster that may cause serious disruption for semiconductor firms. According to 2018 report of Taiwan Central Weather Bureau, a total of 360 typhoons between 1911 and 2017 had caused either a landfall or disaster on lands in Taiwan [61]. These natural disasters (e.g., earthquake and typhoon) can likely cause a domino effect of consequences such as mudslide, flood, and even tsunami with huge damages for industries.

The abovementioned discussion motivates the selection of earthquake and typhoon as major disasters and disruption scenarios for study in the context of this paper. In the following section, backcasting procedures to develop a necessary knowledge based resilient warehouse are illustrated for these scenarios. However, the proposed approach can be similarly applied to other disruptions.

B. BACKCASTING APPLICATION

This study attempts to interpret the past experiences when the case company faced natural disasters of typhoon and earthquake with the backcasting approach. This is an example of post-review. Through post-mortem review, improvement measures are proposed and incorporated into the KW to enhance company’s resilient capability. The
entire review process is in the post-disruption phase, but also can be considered as preparations for the next possible disaster in the pre-disruption phase. Figure 5 illustrates a backcasting framework and its Steps of A, B, C, and D. In Step A, the experience of world class Japanese companies (e.g., Renesas, Tokyo Electron, and Nissan) is adopted to setup the expected time (i.e., within two months) to recovery after a severe earthquake. Partial production lines of Nissan resumed operations on March 16. But, because of awaiting recovery of suppliers, the plants in Tochigi and Iwaki were back on line in April and May, respectively [62]. Renesas took three months to have its NaKa’s 200mm line begun by early June and the 300mm line restarted, a week later [15]. According to the case company’s standards, in case of typhoon, it is recommended that firms should vision their recovery within 2 days (with not severe typhoon level) or from 2 to 7 days (with severe typhoon level). Moreover, in both of earthquake and typhoon disruptions, firms should not suffer any human loss as a desired goal. Physical safety of employees is also one top concern of Nissan.

In Step B, firms need to identify the possible failures that may cause disruptions, review their capabilities to mitigate failures, and align the capabilities with the vision (goal) set up in Step A to determine the gaps from the baseline (or current state) to the desired resilient goal. Step C will propose solutions to fill the gaps identified in Step B. Works to be done include with failures from disruption applying One Point Lesson (OPL) tool to analyze the possible causes and suggesting treatments. OPL is suitable for mining, analyzing, and improving cases. OPL grasps the root cause of the problem. The KW plays a key role at this stage. Knowledge from the past experiences are referred. Finally, in Step D, an action plan composed of a set of SOPs is obtained and performed in the during-disruption phase. The action plan also includes the works and training needed to strengthen preparations in the pre-disruption phase. As mentioned in Section III.B, the drill is one way to initiate a backcasting process. Through drill, the obtained SOPs represents grow-and-learn and will become new knowledge of the KW. In the following two sub-sections, explicit illustrations on Steps B and C for earthquake and typhoon will be discussed, respectively.

**B.1 STEPS B AND C FOR EARTHQUAKE DISRUPTION**

According to the seismic intensity scale, possible risk levels of earthquake are immediately identified by the facilitator team. The scale can be either strong, very strong, or others, that may cause great damage or even major disruption and death. Since business continuity and JIT delivery are major concerning in semiconductor, timing becomes an issue. When a severe earthquake occurs, roads and ports are closed, communication systems are interrupted, and factory buildings are collapsed. The crisis of being unable to fulfill orders, limited transportation, and ineffective communication systems are the three main failures, which also represent critical gaps for the case company to reach a desired resilient goal. For other firms, the concerning gaps could be more depending on what their current levels of resilience are.

For the case company, employees’ safety must be of prime importance. First response post-disaster is to ensure the safety of employees. In fact, firms should concern not only about their employees but also about their suppliers and affiliated factories. Therefore, the possible failures and level of disruptions must be broadcasted to all related departments and people at the first moment.

The case company plays multiple roles in the semiconductor industry. It plays a subcontractor role and delivers products to a distribution center (DC) as agreed, and then the DC ships products to customers. It accepts IDM equipment transfer and is responsible for shipments to these IDM companies. It also has its own major customers and ships products directly to customers. Among them, the situation of delivering products to DC has a stricter contract, because products need to be combined with the arrival of other suppliers. If the contract content is changed due to a disaster, freight forwarder is involved and the difficulty is very high.

With gaps (or failures) identified in Step B, there are creative solutions proposed in Step C to manage with earthquake disruption and OPL is a selective tool. From the perspective of order fulfillment, as stated in Section IV.A, guaranty of promised capacity and JIT are the core of appealing to business continuity. Figure 6 shows an OPL analysis to the failure of unable to fulfill orders.

The earthquake disruption can stop or hinder the fulfillment of customer orders. The case company requires a flexible order fulfillment plan against severe loss. As illustrated in Figure 6, the first proposed solution to this failure is called a flexible order fulfillment allocation policy (70-30), that is, the case company should avoid allocating a big order to one factory, although the case company might do this to enjoy the economy of scale. The case company allocates the big order to different factories in different locations, with the ratio of 70~30 (i.e., 70% order is fulfilled at factory 1 in area A, and 30% order is fulfilled at factory 2 in area B). This conclusion comes from experience and brainstorming discussion. It is a knowledge applied by the case company. In case of earthquake disruption at factory 1, factory 2 may double its capacity to fulfill 60% of the order. The other 40% of the order will be further evaluated (called order fulfilment evaluation) and treated in one of three alternatives: shifted to another factory of their own, outsourced, or shifted to competitors (called substitutes for order fulfilment). The last alternative seems unreasonable. However, in order to guarantee promised capacity and maintain the principle of business continuity, this arrangement has to be made. In summary, the proposed solutions should be conducted together to ensure the effective and consistent benefits. In the event of earthquake,
A - Awareness & Visioning

• Employees safety (no human loss)
• Earthquake: recovery within two months
• Typhoon: recovery within two days (not serious) or two to seven days (serious)

B - Baseline

• Failure identification
• Alignment between failures and capabilities
• Gap identification based on alignment
• The baseline identification will be discussed separately for earthquake and typhoon.

C - Creative Solutions

• SOP-Failure tree-OPL analysis
• Solutions proposed to reduce gaps being identified
• The solutions proposed will be discussed separately for earthquake and typhoon.

D - Down to Actions

• Detailed implementation plan and actions based on solutions being proposed in the during-disruption phase
• Knowledge based resilient warehouse enrichment in both pre- and post-disruption phases

FIGURE 5. BACKCASTING APPROACH FOR DEVELOPING A RESILIENT KW TO EARTHQUAKE DISASTER AND TYPHOON DISASTER.
even though the case company itself can operate normally, but the transportation of supplies (e.g., materials or parts) from suppliers may be blocked, which causes the interruption of company’s operation. Therefore, if the case company and its suppliers only negotiated for a fixed or inflexible supplies’ transportation route or mode, the case company will suffer from the disruption. The proposed solution for this failure is to contract with suppliers for flexible supplies’ transportation routes or modes. In other words, the case company needs its suppliers to offer flexible transportation (by truck, by sea, by railway, or by air cargo) to ensure the timely transport of supplies. Again, cost trade-off will be an issue for the route or mode selection. The decision may follow an SOP. Moreover, a strategic partner arrangement is preferred to ensure that the transportation of supplies to the case company is highly prioritized.

Regarding to the failure of ineffective communication, if the case company does not prepare for an effective communication (e.g., timely notification about earthquake and notification about coordination and safety support to manage with the earthquake), it will seriously suffer from the disruption. Therefore, the earthquake notification short message service (SMS) plays an important role. The case company can contract with Taiwan Central Weather Bureau and telecommunication companies to send notifications about earthquake magnitude to all their employees, making them to be notified and ready to manage with the earthquake. The SMS content also contains a series of disruption relief instructions sent to the relevant personnel of departments. Such SMS notifications enhance pro-activeness and preparation for earthquake throughout the case company. In order to ensure the transmission quality and immediacy, the case company set up a cellular base station in the factory area.

At the case company, the earthquake facilitator team serves as the central nervous system in the during-disruption phase. Once this team is activated at the factory level, it is authorized to make all decisions to resolve disruption. It is specially formed internally to coordinate all the communication to manage with the earthquake disruption. The team includes at least one member from every related department to support and supervise the coordination covering the planning and failure evaluation, and propose the solutions and action plans to deal with the earthquake disruption. The failures and proposed solutions as abovementioned are summarized as in Figure 7.

**B.2 STEPS B AND C FOR TYPHOON DISRUPTION**

The scales of typhoon, which require the case company’s attention, are strong winds, heavy rain, and flooding. Similar to the case of earthquake, ineffective communication can be a failure to resilience when a typhoon disruption happens. Effective communication helps transmit timely notification and coordination to manage the disruption. In addition, the JIT delivery characteristic requires the case company to maintain a coordinated and rhythmic state in all of its production processes, only if the case company has effective communication execution throughout the factory.

Again, when the typhoon facilitator team starts on duty, the team has rights to coordinate all resilient activities. Since typhoons happen often in Taiwan, such a team is a long-term formation at the case company. The knowledge of resilience and resilient assessment learnt from the past is accumulated, and consistently and intensively managed. The knowledge is ensured about how to prepare for, manage with, and recover from typhoon disruptions, and communicated effectively across all related departments of the company. Figure 8 illustrates the possible failures (gaps) to resilience and proposed solutions in the scenario of typhoon disruption.

The failure of resources shutdown, such as electricity or water, is critical for semiconductor production. If there is no substitution plan, production will seriously suffer. The proposed solutions for this failure includes independent resources suppliers, recycled water supplies, and backup data capability.

Besides with the public or local suppliers, the case company contracts with independent resources suppliers to provide electricity or water in case of the public resources shutdown due to a typhoon. These contracts ensure resources to maintain the necessary production. Moreover, in case of water shortage, the case company plans up to 50% recycle capability, based on the past experience, to guarantee sufficient water supplies for manufacturing.

During a typhoon period, the case company may lose its data, which are precious and valuable asset. Therefore, data backup is a proposed solution, such as contracting with a trusted third party to store and restore data. It means the importance to secure data to mitigate the costs and damages from losing data.

To cope with the failure of employees unable to work as usual caused by a typhoon, the case company applies a flexible labor working schedule for employees to ensure that they can come to factory and work. To support a flexible labor working schedule, arrangements for transportation to pick-up employees from their homes to factory as well the incidental food arrangement and preparation are required. The food arrangement and preparation is to equip a cold storage warehouse for food to prepare sufficient meals for employees when they go to work on a typhoon’s day. After concerning the risk and cost trade-off, the case company decides to lease a warehouse under a regular contract instead to purchase space from the spot market in typhoon time.

**C. ASSESSMENT BEHIND THE KW**

With the examples of the case company, the KW for earthquake and typhoon have been discussed in this study. The KW can be evolved to include other natural and non-natural disruptions such as fire, cultural change, and
### One Point Lesson

| Serial No.: | Earthquake _201x_02_13 |
|-------------|------------------------|
| Department: | Taiwan Site |
| Station: | ASSY PLANT |
| Date: | 201x/08/11 |

**Control Item:** Unable to fulfill orders  
**Customer:** JIT, IDM & key customers  
**Specification:**

| When | Who | What | How many | Picture/ Graph |
|------|-----|------|----------|----------------|
| Power tower damage in center Taiwan | Site facilitator | (1) JIT items failure, (2) Key customers urgent for delivery, (3) Typhoon damaged one of two key input power line and power shortage for 2 weeks, (4) Production down as power break for two weeks | (1) JIT items x 52, (2) 25 Key customers complaints (total monthly sales 17%) | |

**Description of Anomaly**  
- A. Timing of finding defect/fault: on 201x_02_25, key customers claimed JIT lost and major order failed to fulfill at airport hub.  
- B. Process of treatment: 1. Identify the possible causes of defect patterns:  
  - (1) No priority rule to re-allocate resource during production recovery,  
  - (2) Sales and PC urge their own customer priority list on expedite finish good, piece parks release and wip inventory,  
  - (3) OEM customers have no support as their dedicated equipment power shut down,  
  - (4) Small volume order was push out in production line as change over lost.  
- Temporary measures: (1) Sales dept. issues customer order fulfillment priority list, (2) Production line auto shift to available power-on line base on piece parks inventory to continue run, (3) When production is recovery, item 1 and item 2 conflict, GM call VP, facilitators and customer PM to allocate available production capacity and priority customer orders.  
- Root causes: (1) Earthquake recovery SOP didn’t cover customer order fulfillment priority during production recovery, (2) Unable to fulfill orders, (3) No backup plan for OEM customers.  
- Handling: (1) Outsource customer order to other sites, standard BOM. Reallocate power line to JIT / OEM equipment, (2) OEM, JIT (without standard BOM). Daily communication to update status.

**Real Cause Exploration**  
- 1. No conscious sense among sales, production line and PC people during recovery period.  
- 2. PC group fulfill 100% customer order in single one allocated site.

**Solutions for Preventing Recurrence**  
- Facilitator team involved in and set up SOP during recovery period.  
- More backup or alternative power line for JIT/OEM equipment.

**Proposed Temporary Measures**  
- Date of Enforcement: /Executor:  
- Partial or overall JIT / OEM equipment lack of power cause production stop.

**Real Cause Exploration**  
- Machine

**Solutions for Preventing Recurrence**  
- Machine

**Proposed Temporary Measures**  
- Date of Enforcement: /Executor:  
- Date of Enforcement: /Executor:  
- Date of Enforcement: /Executor:  

**Proposed Temporary Measures**

**Real Cause Exploration**

**Solutions for Preventing Recurrence**

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**Specification / ECN:** Renew power shut down SOP, Order fulfillment policy  
**Effective Date:** 201x/04/1  
**Status:** Close  
**Updated Date:** 
**Audit Supervisor:** Date:

**Keywords:** Earthquake, Power break, JIT, Order fulfillment, Capacity allocation, Substitutes for order fulfillment, 70-30.

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**FIGURE 6. AN OPL ANALYSIS TO THE FAILURE OF UNABLE TO FULFILL ORDERS.**
Awareness of two months recovery time and no fatal loss

Major concerning: Continuity and JIT delivery

Gaps to Resilient (Failures)  Proposed Solutions

- Unable to fulfill orders
  - Flexible order fulfillment allocation policy (70-30)
- Limited transportation
  - Order fulfillment evaluation
  - Substitutes for order fulfillment
- Ineffective communication
  - Contact with suppliers for flexible supply transportation
  - Earthquake notification SMS
  - Earthquake facilitator team activates duty

FIGURE 7. POSSIBLE FAILURES AND PROPOSED SOLUTIONS TO REACH RESILIENCE (EARTHQUAKE).

Awareness of 2-7 days recovery time and no fatal loss

Major concerning: Continuity and JIT delivery

Gaps to Resilient (Failures)  Proposed Solutions

- Ineffective communication
  - Typhoon notification
- Resources shutdown
  - Typhoon facilitator team activates duty
- Employees unable to work as usual
  - Independent resource suppliers
  - Recycled water supplies
  - Back up data capability
  - Transportation arrangement
  - Food arrangement and preparation

FIGURE 8. POSSIBLE FAILURES AND PROPOSED SOLUTIONS TO REACH RESILIENCE (TYphoon).
**FIGURE 9. PERFORMANCE OF THE RESILIENT KW.**

**FIGURE 10. PARETO FRONTIER CURVE.**

Can improve factor one or/and factor two to move toward the future frontier.
financial risk. The demonstrated backcasting approach and its ABCD analysis are helpful for this purpose. In terms of the KW implementation and continual improvement, Figure 9 shows the case company’s recovery time difference between 2007 and 2015 from typhoon disruptions. A 64% time reduction has been achieved.

VI. CONCLUSIONS AND FUTURE RESEARCH

This study develops a framework, which integrates the backcasting approach and ABCD analysis, to construct a KW for semiconductor assembly and testing firms. It extends backcasting applications to a new field of SCRES. A world-class case company is selected to aid understanding of how a KW is developed by backcasting on earthquake and typhoon disruptions, thereby validating the applicability of the proposed framework. Several recommendations are observed.

Firms should be aware of and pay special attention to SCRES. The awareness helps firms prepare and plan ahead to manage unexpected hazards during their business operations. Firms should proactively make a comprehensive plan and efforts for unexpected hazards and disruptions, from the early state of their operations, with regular and consistent checking and evaluation during their operations, to ensure the readiness of capabilities for response and recovery across organizational functions. These plans and efforts should prevent firms from long and severe discontinuity of their business, and as a result, help firms save tremendous costs and expenditures during their recovery from the disruption.

To have a comprehensive and consistent recovery plan, firms must set up a vision in terms of a recovery level and time. Such vision must be reasonably measured and assessed from a firm’s capacities and needs to be re-evaluated regularly and updated to align with the state of the firm. Firms should make a baseline evaluation of their current status. Then, firms need to focus on the prediction and identification of possible failures to their operations and align the possible failures with all the processes across their functional departments. The alignment should help firms identify and evaluate the gaps between their current capabilities and the vision targets of their resilience and recovery in the event of disruption. Furthermore, firms should propose solutions to address the gaps and then make a detailed implementation of their solutions into practice. The implementation must be followed strictly and regularly checked and updated to ensure that the implementations are well aligned with firm’s capabilities and the gaps to resilience.

Regular update, evaluation, and reporting are critical in SCRES. Such issues ensure firms comprehensively evaluate their preparation for the disruption and make appropriate enhancement and improvement for the resilience plan. Creating a “culture” of update, checking and reporting does matter. Therefore, a team should be formed to facilitate all resilient activities. The KW requires information transparency, sharing and accessibility to guarantee resilience communication throughout the entire firm. This is also a part of facilitator team’s responsibility.

Future extension may include at least the following two directions. The assessment of a firm’s resilient capability is one important research subject. In fact, the schema of Figure 1 has revealed some recommendations. The eleven key elements listed correspond to different resilient capabilities. If the relationship between elements and capabilities is explicitly identified, a firm’s resilience can be easily measured by converting these elements into indicators and calculating their weights. Furthermore, benchmarking the best practice in the sector and making comparison with it via a radar chart, a firm can detect a direction to improve the resilience. Second, if the mathematical function of a firm’s resilience can be found and represented by a Pareto frontier curve as shown in Figure 10, research on the strategic planning can be further evaluated. For example, which factor to start with or multiple factors are to be considered simultaneously to improve the resilience of the firm (i.e., outward moving of the curve). The upper limit of the cost that firms are willing to pay and the pre-defined recovery time mutually affect the span of the curve moving outward.

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REFERENCES

[1] J. P. Ribeiro and A. Barbosa-Povoa, "Supply chain resilience: Definitions and quantitative modelling approaches - A literature review," Computers & Industrial Engineering, vol. 115, pp. 109-122, 2018.
[2] H. Adobor, "Supply chain resilience: An adaptive cycle approach," International Journal of Logistics Management, vol. 31, no. 3, pp. 443-463, 2020.
[3] S. N. Emenike and G. Falcone, "A review on energy supply chain resilience through optimization," Renewable & Sustainable Energy Reviews, vol. 134, p. Article No. 110088, 2020.
[4] Shashi, P. Centobelli, R. Cerchione, and M. Ertz, "Managing supply chain resilience to pursue business and environmental strategies," Business Strategy and The Environment, vol. 29, no. 3, pp. 1215-1246, 2020.
[5] J. Z. Chen, H. F. Wang, and R. Y. Zhong, "A supply chain disruption recovery strategy considering product change under COVID-19,” Journal of Manufacturing Systems, vol. 60, pp. 920-927, 2021.
[6] R. Rajesh, "Flexible business strategies to enhance resilience in manufacturing supply chains: An empirical study," Journal of Manufacturing Systems, vol. 60, pp. 903-919, 2021.
[7] A. Salamai, O. K. Hussain, M. Saberi, E. Chang, and F. K. Hussain, "Highlighting the importance of considering the impacts of both external and internal risk factors on operational parameters to improve supply chain risk management," IEEE Access, vol. 7, pp. 49297-49315, 2019.
[8] X. L. Liu, Z. W. Dou, and W. Yang, "Research on influencing factors of cross border e-commerce supply chain resilience based on
integrated fuzzy DEMATEL-ISM,” *IEEE Access*, vol. 9, pp. 36140-36153, 2021.

[9] A. Ali, A. Mahfouz, and A. Arisha, “Analyzing supply chain resilience: Integrating the constructs in a concept mapping framework via a systematic literature review,” *Supply Chain Management-an International Journal*, vol. 22, no. 1, pp. 16-39, 2017.

[10] M. H. Chowdhury and M. Quaddus, “Supply chain resilience: Conceptualization and scale development using dynamic capability theory,” *International Journal of Production Economics*, vol. 188, pp. 185-204, 2017.

[11] Y. Ni, Y. Cheng, and F. Xiong, “Integrated optimization of multiple warehouse replenishment for semiconductor manufacturing,” *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 39, pp. 4601-4612, 2017.

[12] Y. H. Lee, S. Chung, B. Lee, and K. H. Kang, “Supply chain model for the semiconductor industry in consideration of manufacturing characteristics,” *Production Planning & Control*, vol. 17, no. 5, pp. 518-533, 2006.

[13] J. Lyu, C. W. Liang, and P. S. Chen, “A data-driven approach for identifying possible manufacturing processes and production parameters that cause product defects: A thin-film filter company case study,” *IEEE Access*, vol. 8, pp. 49395-49411, 2020.

[14] W. Shi and M. Persson, “Renesas Electronics and the automotive microcontroller supply chain (A),” Harvard Business School Case 612-071, 2012.

[15] J. Yoshida, “Post quake: The finest hour of Renesas and the industry,” [https://www.edn.com/post-quake-the-finest-hour-of-renesas-and-the-industry](https://www.edn.com/post-quake-the-finest-hour-of-renesas-and-the-industry) (accessed December 9, 2021).

[16] W. Ho, T. Zheng, H. Yildiz, and S. Talluri, “Supply chain risk management: A literature review,” *International Journal of Production Research*, vol. 53, no. 16, pp. 5031-5069, 2015.

[17] T. Kieras, J. Farooq, and Q. Y. Zhu, “I-SCRAM: A framework for iot supply chain risk analysis and mitigation decisions,” *IEEE Access*, vol. 9, pp. 29827-29840, 2021.

[18] J.-H. Thun and D. Schmid, “An empirical analysis of supply chain risk management in the German automotive industry,” *International Journal of Production Economics*, vol. 131, no. 1, pp. 242-249, 2011.

[19] C. Li, C. W. Y. Wong, C. C. Yang, K. C. Shang, and T. C. Lin, “Value of supply chain resilience: Roles of culture, flexibility, and integration,” *International Journal of Physical Distribution & Logistics Management*, vol. 50, no. 1, pp. 80-100, 2019.

[20] G. Behzadi, M. J. O’Sullivan, and T. L. Olsen, “On metrics for supply chain risk,” *European Journal of Operational Research*, vol. 287, no. 1, pp. 145-158, 2020.

[21] Y. Han, W. K. Chong, and D. Li, “A systematic literature review of the capabilities and performance metrics of supply chain resilience,” *International Journal of Production Research*, vol. 58, no. 15, pp. 4541-4566, 2020.

[22] B. Walker and D. Salt, *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press, 2015.

[23] S. Hosseini, A. A. Khaled, and M. Sarde, “A general framework for assessing system resilience using Bayesian networks: A case study of sulfuric acid manufacturer,” *Journal of Manufacturing Systems*, vol. 41, pp. 211-227, 2016.

[24] E. Hollnagel, D. D. Woods, and N. Leveson, *Resilience Engineering: Concepts and Precepts*. Burlington, VT, USA: Ashgate Publishing, Ltd, 2006.

[25] C. S. Holling, “Resilience and stability of ecological systems,” *Annual Review of Ecology and Systematics*, vol. 4, pp. 1-23, 1973.

[26] S. S. Luthar, D. Cicchetti, and B. Becker, “The construct of resilience: A theoretical analysis and guidelines for future work,” *Child Development*, vol. 71, no. 3, pp. 543-562, 2000.

[27] H. Kaur and S. P. Singh, “Disaster resilient proactive and reactive procurement models for humanitarian supply chain,” *Production Planning & Control*, p. In Press, 2020.

[28] V. M. Grötsch, C. Blome, and M. C. Schleper, “Antecedents of proactive supply chain risk management – A contingency theory perspective,” *International Journal of Production Research*, vol. 51, no. 10, pp. 2842-2867, 2013.

[29] M. Christophor and H. Peck, “Building the resilient supply chain,” *The International Journal of Logistics Management*, vol. 15, no. 2, pp. 1-14, 2004.
“Applying ABCD method,” Technological Forecasting and Social Change, vol. 124, pp. 114-125, 2017.

The Natural Step. "Applying ABCD method." http://www.naturalstep.ca/abcd (accessed December 9, 2021).

A. Camarillo, J. Rios, and K. D. Althoff, “Knowledge-based multi-agent system for manufacturing problem solving process in production plants,” Journal of Manufacturing Systems, vol. 47, pp. 115-127, 2018.

U. A. Force, “Integrated computer integrated manufacturing (ICAM) architecture, Part II, Vol. IV--functional modelling manual (IDEF0),” Air Force Material Laboratory, Wright-Patterson AFB, Ohio 45433, AFWAL-TR-81-4023, 1981.

The Natural Step. "ABCD method." http://www.naturalstep.ca/abcd (accessed December 9, 2021).

M. A. V. Borges and L. M. Vieira, "Brazil moving up in the semiconductor global chain," Journal of Operations and Supply Chain Management, vol. 7, no. 1, pp. 68-84, 2014.

C.-F. Chien, H. Ehm, J. Fowler, and L. Mönch, "Modeling and analysis of semiconductor supply chains (Dagstuhl Seminar 16062)," Dagstuhl Reports, vol. 6, no. 2, pp. 28-64, 2016.

J. Lyu, P.-S. Chen, and W.-T. Huang, “Combining an automatic material handling system with lean production to improve outgoing quality assurance in a semiconductor foundry,” Production Planning & Control, vol. 32, no. 10, pp. 829-844, 2021.

McKinsey. "McKinsey on semiconductor." https://www.mckinsey.com/~/media/McKinsey/Industries/Semiconductors/Ours%20Insights/McKinsey%20on%20Semiconductors%20Issues%202017/McK_Semiconductors_Oct2019-Full%20Book-V12-RGB.pdf (accessed December 9, 2021).

B. Oskin. "Japan earthquake and tsunami of 2011: Facts and information." https://www.livescience.com/39110-japan-2011-earthquake-tsunami-facts.html (accessed December 9, 2021).

M. Kazama and T. Noda, "Damage statistics (Summary of the 2011 off the pacific coast of Tohoku earthquake damage),” Soils and Foundations, vol. 52, no. 5, pp. 780-792, 2012.

TCWB. "Earthquakes: Earthquake reports." https://cwb.gov.tw/EN-US/earthquake/data (accessed December 9, 2021).

S. Aggarwal and M. K. Srivastava, "Nissan: Recovering supply chain operation, management development institute," Ivey Publishing, 2016.

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