

Received December 20, 2021, accepted December 27, 2021, date of publication December 31, 2021, date of current version January 12, 2022.

Digital Object Identifier 10.1109/ACCESS.2021.3139912

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

DAH-CHUAN GONG^{1,2}, T. C. HOU³, PHUONG HOANG¹,
BRETT PETERS⁴, AND PING-SHUN CHEN³

¹Department of Industrial and Business Management, Chang Gung University, Taoyuan 33302, Taiwan

²Supply Chain Division, Chang Gung Memorial Hospital-Linkou, Taoyuan 33302, Taiwan

³Department of Industrial and Systems Engineering, Chung Yuan Christian University, Taoyuan 320314, Taiwan

⁴College of Engineering and Applied Science, University of Wisconsin-Milwaukee, Milwaukee, WI 53211, USA

Corresponding author: Ping-Shun Chen (pingshun@cycu.edu.tw)

This work was supported in part by the Chang Gung Memorial Hospital-Linkou under Grant BMRPE93.

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

The associate editor coordinating the review of this manuscript and approving it for publication was Justin Zhang.

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 had 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 Hoseini *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 step-wise 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 capably 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 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.

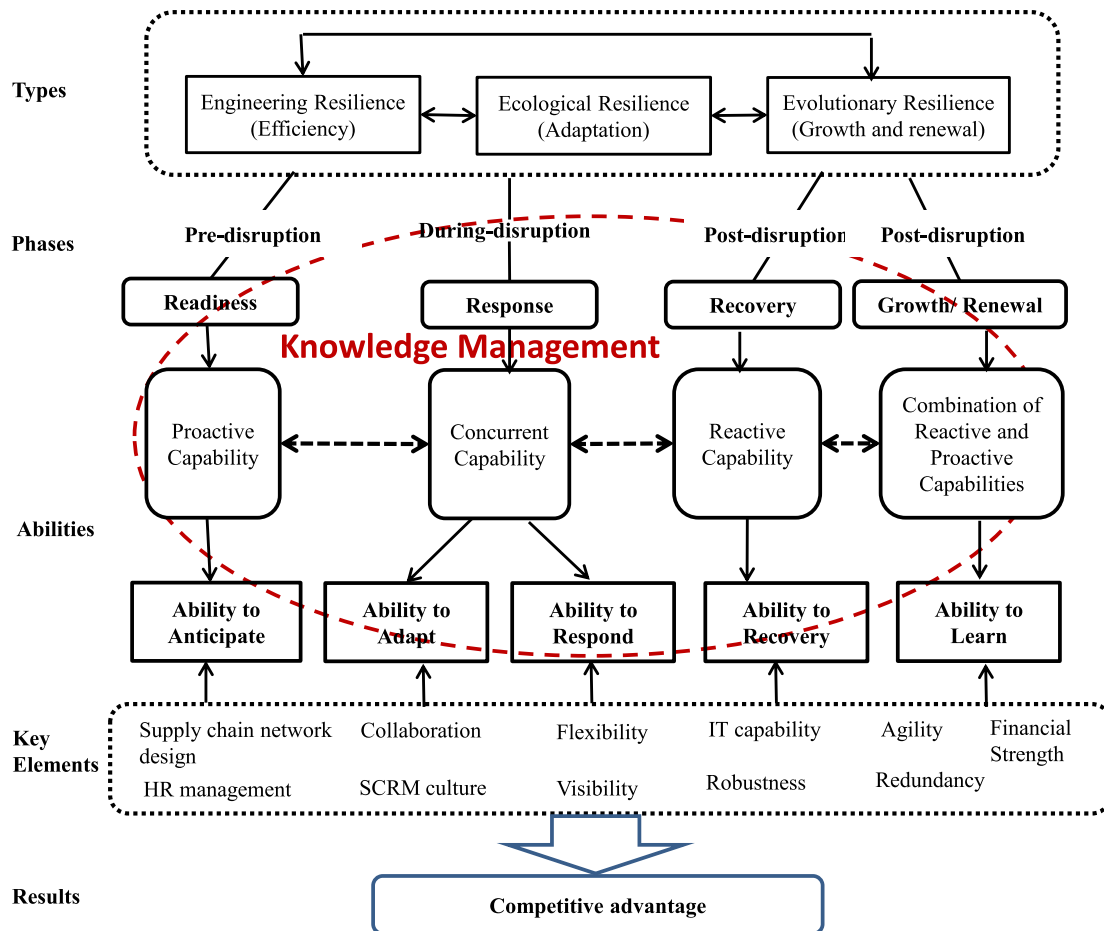


FIGURE 1. A comprehensive view of SCRES.

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.

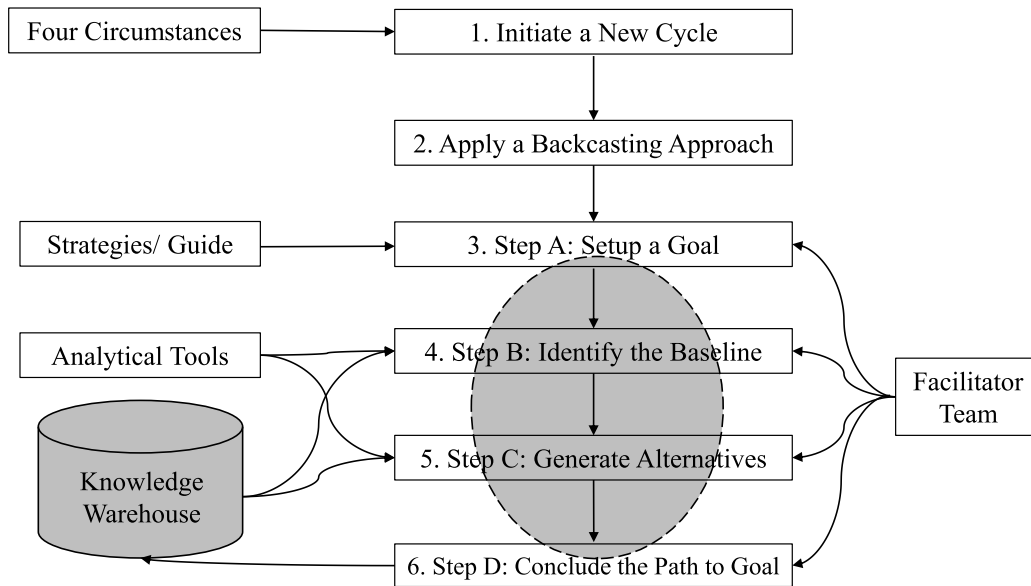
Knowledge comes from experience and learning, including academic and practical learning [52]. Knowledge can be accumulated through continual training, learning, and evolving. Basically, there are four types of circumstances that trigger a cycle of learning to accumulate experience and enrich knowledge. 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



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.

(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 oversea 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, A_1 is denoted as for the Step A in dealing with earthquake alone. B_1 , C_1 , and D_1 are corresponding steps associated with A_1 . The knowledge based resilient warehouse KW_1 supports the development process of this cycle. KW_1 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 A_{1+2} . Corresponding notations, B_{1+2} , C_{1+2} , and D_{1+2} , are used to replace B_1 , C_1 , and D_1 , respectively. The vision in A_{1+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 (B_1) shall be differed from B_{1+2} , so are C_1 vs. C_{1+2} and D_1 vs. D_{1+2} .

KW_1 is referred in the analysis process of A_1 , B_1 , C_1 , and D_1 . On the other hand, KW_{1+2} is for the analysis of

A_{1+2} , B_{1+2} , C_{1+2} , and D_{1+2} . However, KW_1 is not necessary a subset of KW_{1+2} . KW_1 will not be removed due to the appearance of KW_{1+2} , because KW_1 corresponds to the occurrence of earthquake alone. In forming the KW_{1+2} , it is possible to remove a portion from KW_1 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 KW_1 to KW_{1+2} can also be applied between two similar cases (or failures). This is to find SOPs for a similar case from the existing KW_1 , adjust them, and apply them to the new case (KW_{1+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 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

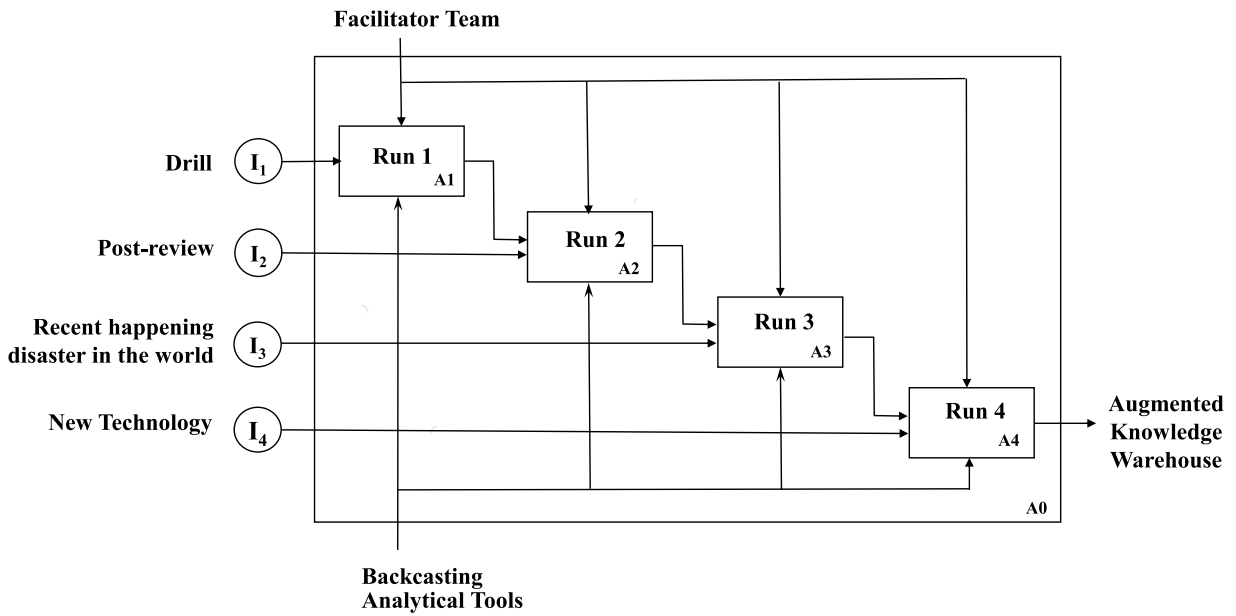


FIGURE 3. An IDEF0 representation in developing a KW.

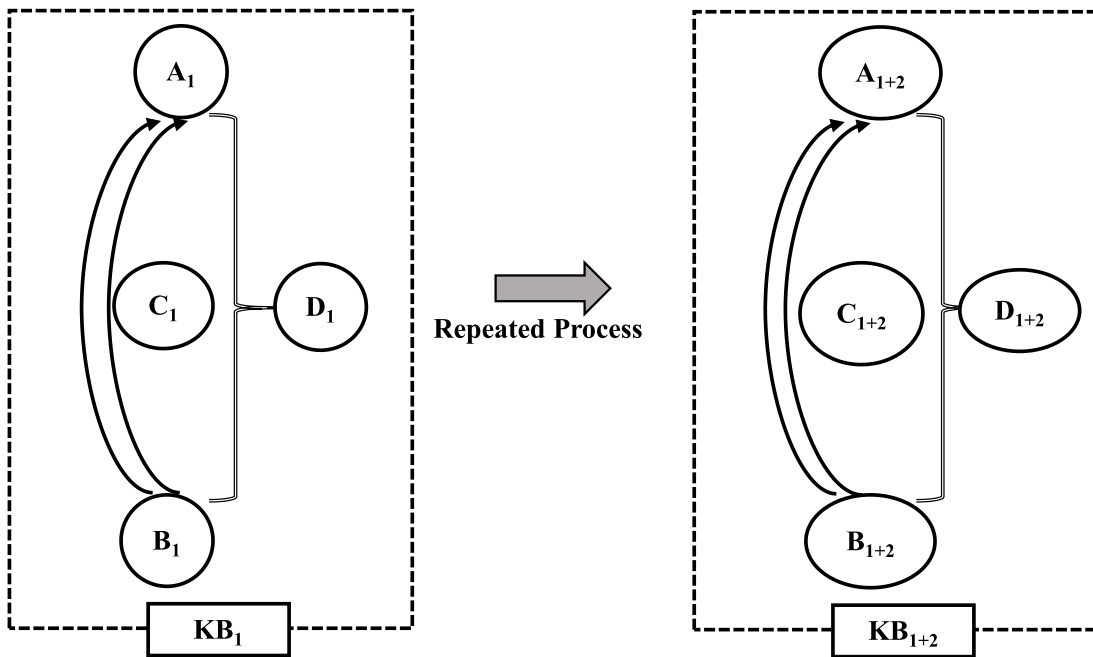


FIGURE 4. An expanded schema of loop ABCD.

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 Iwoki 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

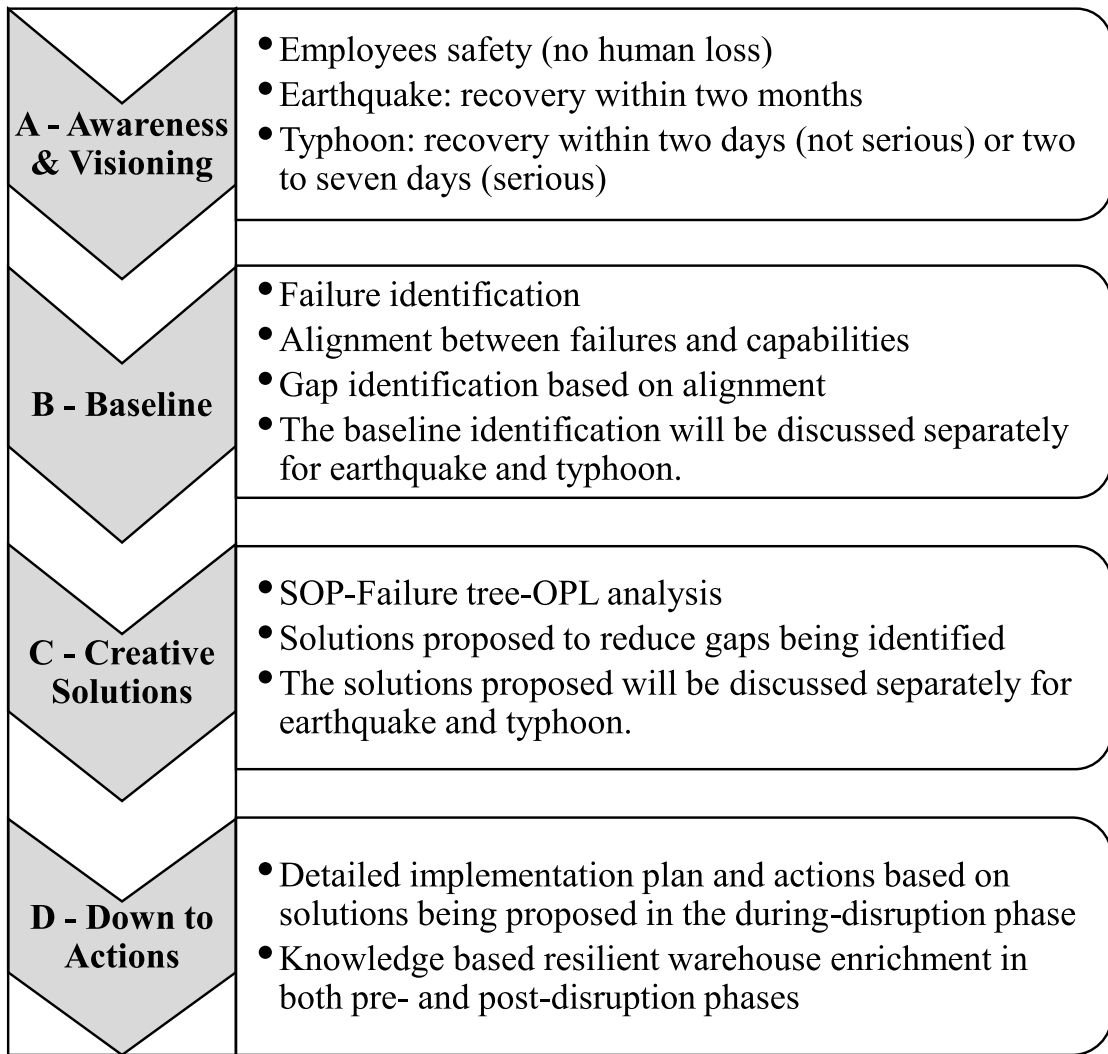


FIGURE 5. Backcasting approach for developing a resilient KW to earthquake disaster and typhoon disaster.

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.

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 fulfilment of customer orders. The case company requires a flexible order fulfilment plan against severe loss. As illustrated in Figure 6, the first proposed solution to this failure is called a flexible order fulfilment 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, 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.

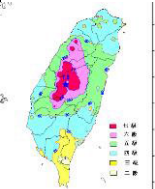
2) STEPS B AND C FOR TYPHOON DISRUPTION

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

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:		Principal:	Site facilitator team
Description of Anomaly		Proposed Temporary Measures		Real Cause Exploration		Solutions for Preventing Recurrence	
When	power tower damage in center Taiwan	<p>A. Timing of finding defect/fault: on 201x_02_25, key customers claimed JIT lost and major order failed to fulfill at airport hab. 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. 2. Tempory 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. 3. 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. 4. 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.</p>	Man-Made	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.	Man-Made	Facilitator team involved in and set up SOP during recovery period _ Order fulfillment evaluation	
Who	site facilitator			Date of Enforcement: /Executor:		Date of Enforcement: /Executor:	
What	(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		Machine	Partial or overall JIT / OEM equipment lack of power cause production stop.	Machine	More backup or alternative power line for JIT/ OEM equipment.	
Where	center Taiwan Power towel			Date of Enforcement: /Executor:		Date of Enforcement: /Executor:	
How many	(1) JIT items x 52, (2) 25 Key customers complaints (total monthly sales 17%)		Material		Material		
Picture/ Graph				Date of Enforcement: /Executor:		Date of Enforcement: /Executor:	
		Method	1. No SOP for order fulfillment priority during recovery period, 2. Big order allocated in one site in one factory, 3. No backup capacity planning arranged by other factory or other sites, 4. No outsource plan for major orders, 5. Bad relation set up with competitors who run biz with our customers.	Method	1. 70-30 allocation agreement on sales order (major site 70%, backup site 30%), 2. Backup site can double capacity from 30% to 60% loading when major site lost, 3. Substitutes for order fulfillment, 4. PC system quarterly simulate order reallocate per nature disaster case.		
		Date of Enforcement: /Executor:	Date of Enforcement: /Executor:	Date of Enforcement: /Executor: Site facilitator team			
Standard-ization	Specification /ECN:	Renew power shut down SOP, Order fulfillment policy		Close	Status:	Updated Date:	
	Effective Date:	201x/4/1			Audit Supervisor	Date:	

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

FIGURE 6. An OPL analysis to the failure of unable to fulfill orders.

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

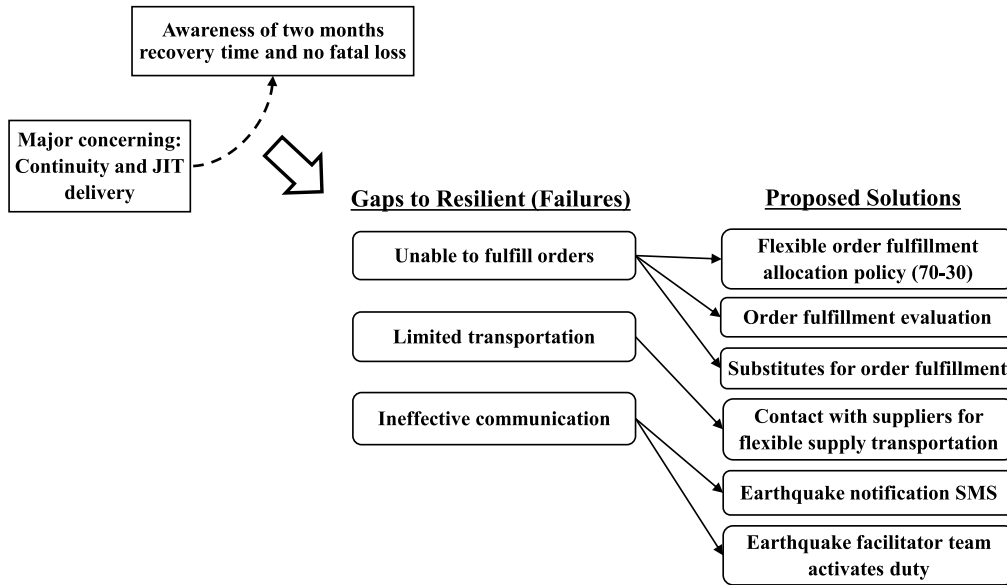


FIGURE 7. Possible failures and proposed solutions to reach resilience (earthquake).

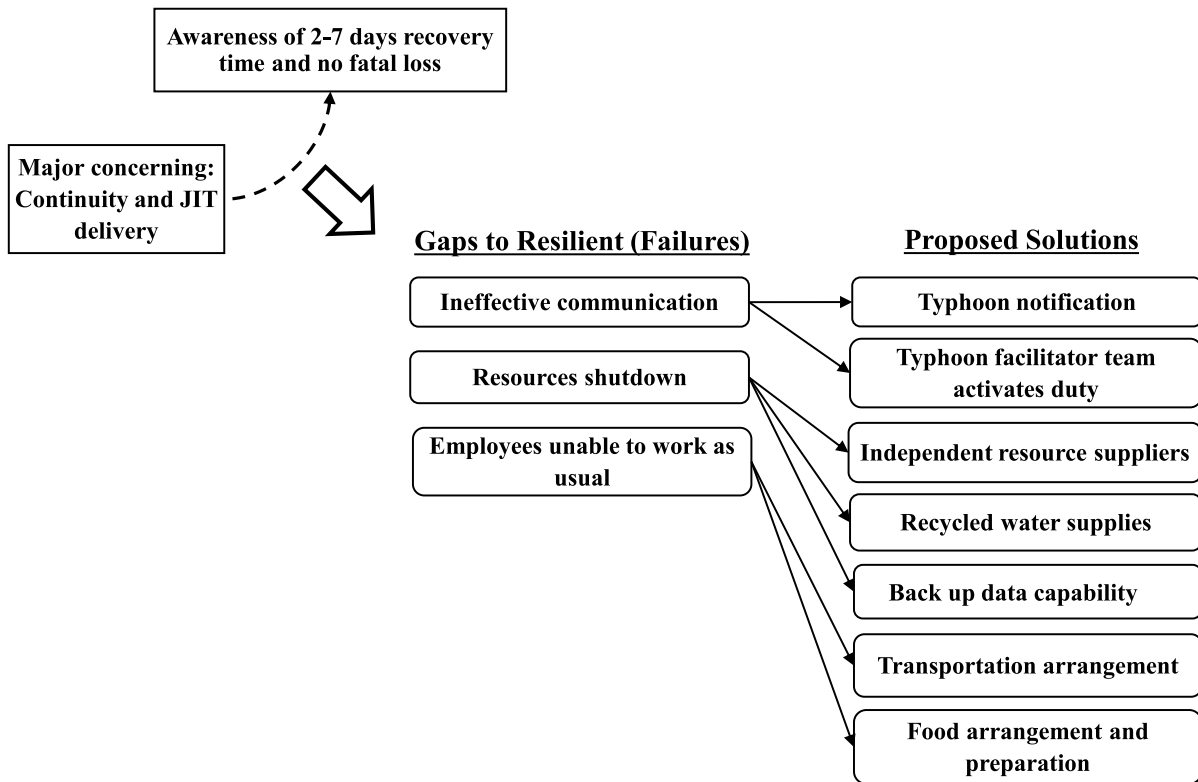


FIGURE 8. Possible failures and proposed solutions to reach resilience (typhoon).

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.

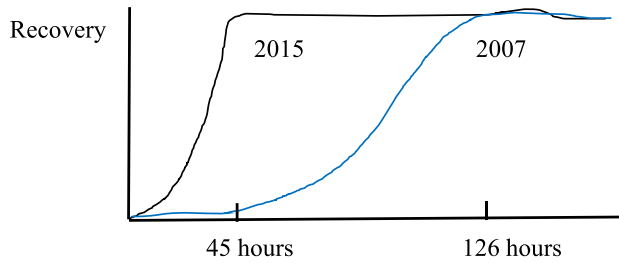


FIGURE 9. Performance of the resilient KW.

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 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. CONCLUSION 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.

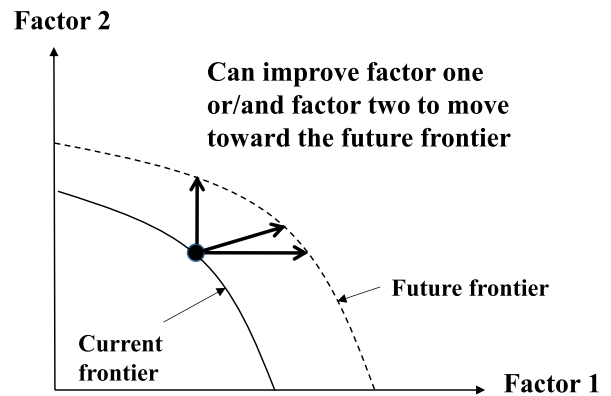


FIGURE 10. Pareto frontier curve.

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.

REFERENCES

- [1] J. P. Ribeiro and A. Barbosa-Povoa, "Supply chain resilience: Definitions and quantitative modelling approaches—A literature review," *Comput. Ind. Eng.*, vol. 115, pp. 109–122, Jan. 2018.
- [2] H. Adobor, "Supply chain resilience: An adaptive cycle approach," *Int. J. Logistics Manage.*, vol. 31, no. 3, pp. 443–463, Aug. 2020.
- [3] S. N. Emenike and G. Falcone, "A review on energy supply chain resilience through optimization," *Renew. Sustain. Energy Rev.*, vol. 134, Dec. 2020, Art. no. 110088.
- [4] S. Kashav, P. Centobelli, R. Cerchione, and M. Ertz, "Managing supply chain resilience to pursue business and environmental strategies," *Bus. Strategy Environ.*, vol. 29, no. 3, pp. 1215–1246, Mar. 2020.
- [5] J. Chen, H. Wang, and R. Y. Zhong, "A supply chain disruption recovery strategy considering product change under COVID-19," *J. Manuf. Syst.*, vol. 60, pp. 920–927, Jul. 2021.
- [6] R. Rajesh, "Flexible business strategies to enhance resilience in manufacturing supply chains: An empirical study," *J. Manuf. Syst.*, vol. 60, pp. 903–919, Jul. 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. Liu, Z. 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, "Analysing supply chain resilience: Integrating the constructs in a concept mapping framework via a systematic literature review," *Supply Chain Manage., Int. J.*, vol. 22, no. 1, pp. 16–39, Jan. 2017.
- [10] M. M. H. Chowdhury and M. Quaddus, "Supply chain resilience: Conceptualization and scale development using dynamic capability theory," *Int. J. Prod. Econ.*, vol. 188, pp. 185–204, Jun. 2017.
- [11] Y. Ni, Y. Cheng, and F. Xiong, "Integrated optimization of multiple warehouse replenishment for semiconductor manufacturing," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 39, no. 11, pp. 4601–4612, Nov. 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," *Prod. Plan. Control*, vol. 17, no. 5, pp. 518–533, Jul. 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. Shih and M. Pierson, *Renesas Electronics and the Automotive Microcontroller Supply Chain (A)*, document 612-071, Harvard Bus. School Case, 2012.
- [15] J. Yoshida, *Post Quake: 'The Finest Hour' of Renesas and the Industry*. Accessed: Dec. 9, 2021. [Online]. Available: <https://www.edn.com/post-quake-the-finest-hour-of-renesas-and-the-industry/>
- [16] W. Ho, T. Zheng, H. Yildiz, and S. Talluri, "Supply chain risk management: A literature review," *Int. J. Prod. Res.*, vol. 53, no. 16, pp. 5031–5069, 2015.
- [17] T. Kieras, J. Farooq, and Q. 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. Hoening, "An empirical analysis of supply chain risk management in the German automotive industry," *Int. J. Prod. Econ.*, vol. 131, no. 1, pp. 242–249, 2011.
- [19] C. Li, C. W. Y. Wong, C.-C. Yang, K.-C. Shang, and T.-C. Lirn, "Value of supply chain resilience: Roles of culture, flexibility, and integration," *Int. J. Phys. Distrib. Logistics Manage.*, vol. 50, no. 1, pp. 80–100, Dec. 2019.
- [20] G. Behzadi, M. J. O'Sullivan, and T. L. Olsen, "On metrics for supply chain resilience," *Eur. J. Oper. Res.*, vol. 287, no. 1, pp. 145–158, Nov. 2020.
- [21] Y. Han, W. K. Chong, and D. Li, "A systematic literature review of the capabilities and performance metrics of supply chain resilience," *Int. J. Prod. Res.*, vol. 58, no. 15, pp. 4541–4566, Aug. 2020.
- [22] B. Walker and D. Salt, *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Washington, DC, USA: Island Press, 2015.
- [23] S. Hosseini, A. Al Khaled, and M. Sarder, "A general framework for assessing system resilience using Bayesian networks: A case study of sulfuric acid manufacturer," *J. Manuf. Syst.*, vol. 41, pp. 211–227, Oct. 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," *Annu. Rev. Ecol. Syst.*, vol. 4, no. 1, pp. 1–23, 1973.
- [26] S. S. Luthar, D. Cicchetti, and B. Becker, "The construct of resilience: A critical evaluation and guidelines for future work," *Child Develop.*, vol. 71, no. 3, pp. 543–562, May 2000.
- [27] H. Kaur and S. P. Singh, "Disaster resilient proactive and reactive procurement models for humanitarian supply chain," *Prod. Plan. Control*, to be published, pp. 1–14, doi: [10.1080/09537287.2020.1834124](https://doi.org/10.1080/09537287.2020.1834124).
- [28] V. M. Grötsch, C. Blome, and M. C. Schleper, "Antecedents of proactive supply chain risk management—A contingency theory perspective," *Int. J. Prod. Res.*, vol. 51, no. 10, pp. 2842–2867, May 2013.
- [29] M. Christopher and H. Peck, "Building the resilient supply chain," *Int. J. Logistics Manage.*, vol. 15, no. 2, pp. 1–14, 2004. [Online]. Available: <https://www.emerald.com/insight/content/doi/10.1108/09574090410700275/full/html>
- [30] J. B. Rice and F. Caniato, "Building a secure and resilient supply network," *Supply Chain Manag. Rev.*, vol. 7, no. 5, pp. 22–30, 2003.
- [31] H. Adobor and R. S. McMullen, "Supply chain resilience: A dynamic and multidimensional approach," *Int. J. Logistics Manage.*, vol. 29, no. 4, pp. 1451–1471, Oct. 2018.
- [32] Y. Sheffi and J. B. A. Rice, "A supply chain view of the resilient enterprise," *Sloan Manage. Rev.*, vol. 47, no. 1, pp. 41–48, Jan. 2005.
- [33] P. Datta, "Supply network resilience: A systematic literature review and future research," *Int. J. Logistics Manage.*, vol. 28, no. 4, pp. 1387–1424, Nov. 2017.
- [34] N.-O. Hohenstein, E. Feisel, E. Hartmann, and L. Giunipero, "Research on the phenomenon of supply chain resilience: A systematic review and paths for further investigation," *Int. J. Phys. Distrib. Logistics Manage.*, vol. 45, nos. 1–2, pp. 90–117, Mar. 2015.
- [35] T. J. Pettit, J. Fiksel, and K. L. Croxton, "Ensuring supply chain resilience: Development of a conceptual framework," *J. Bus. Logistics*, vol. 31, no. 1, pp. 1–21, Mar. 2010.
- [36] C. G. Kochan and D. R. Nowicki, "Supply chain resilience: A systematic literature review and typological framework," *Int. J. Phys. Distrib. Logistics Manage.*, vol. 48, no. 8, pp. 842–865, 2018.
- [37] B. N. Tran and D.-C. Gong, *Supply Chain Resilience: The Evolution and a Systematic Literature Review*. Taoyuan City, Taiwan: Unpublished Report, Chang Gung Univ., Taiwan, 2019.
- [38] T. J. Pettit, "Supply chain resilience: Development of a conceptual framework, an assessment tool and an implementation process." Ph.D. thesis, Dept. Bus. Admin., Ohio State Univ., Columbus, OH, USA, 2008.
- [39] G. A. Zsidisin and M. E. Smith, "Managing supply risk with early supplier involvement: A case study and research propositions," *J. Supply Chain Manage.*, vol. 41, no. 4, pp. 44–57, Nov. 2005.
- [40] D. Simchi-Levi and W. Schmidt, *Nissan Motor Company Ltd: Building Operational Resiliency*. Cambridge, MA, USA: MIT Sloan Management, 2013.
- [41] S. Alhawari, L. Karadsheh, A. N. Talet, and E. Mansour, "Knowledge-based risk management framework for information technology project," *Int. J. Inf. Manage.*, vol. 32, no. 1, pp. 50–65, Feb. 2012.
- [42] S. Shan, L. Wang, L. Li, and Y. Chen, "An emergency response decision support system framework for application in e-government," *Inf. Technol. Manage.*, vol. 13, no. 4, pp. 411–427, Dec. 2012.
- [43] D. Mourtzis and M. Doukas, "Knowledge capturing and reuse to support manufacturing of customised products: A case study from the mould making industry," *Proc. CIRP*, vol. 21, pp. 123–128, Jan. 2014.
- [44] A. Baydoun and J. El-Den, "A framework for knowledge based software service supply chain (SSSC): A comparative analysis with existing frameworks," *Proc. Comput. Sci.*, vol. 124, pp. 205–215, Jan. 2017.
- [45] Y. Huang, W. Xu, and C. Li, "Information integration framework for a public-private partnership system of an urban railway transit project (Part a: System architecture)," *J. Ind. Inf. Integr.*, vol. 25, Jan. 2022, Art. no. 100244.
- [46] S. Byggeth, G. Broman, and K.-H. Robèrt, "A method for sustainable product development based on a modular system of guiding questions," *J. Cleaner Prod.*, vol. 15, no. 1, pp. 1–11, Jan. 2007.
- [47] D.-C. Gong and J.-L. Chen, "Critical control processes to fulfil environmental requirements at the product development stage," *Int. J. Comput. Integr. Manuf.*, vol. 25, no. 6, pp. 457–472, Jun. 2012.
- [48] J. Quist and P. Vergragt, "Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework," *Futures*, vol. 38, no. 9, pp. 1027–1045, Nov. 2006.

- [49] G. G. Mandujano, J. Quist, and J. Hamari, "Gamification of backcasting for sustainability: The development of the gameful backcasting framework (GAMEBACK)," *J. Cleaner Prod.*, vol. 302, Jun. 2021, Art. no. 126609.
- [50] Y. Kishita, B. C. McLellan, D. Giurco, K. Aoki, G. Yoshizawa, and I. C. Handoh, "Designing backcasting scenarios for resilient energy futures," *Technol. Forecasting Social Change*, vol. 124, pp. 114–125, Nov. 2017.
- [51] The Natural Step. *Applying ABCD Method*. Accessed: Dec. 9, 2021. [Online]. Available: <http://www.naturalstep.ca/abcd>
- [52] A. Camarillo, J. Ríos, and K. Althoff, "Knowledge-based multi-agent system for manufacturing problem solving process in production plants," *J. Manuf. Syst.*, vol. 47, pp. 115–127, Apr. 2018.
- [53] *Integrated Computer Integrated Manufacturing (ICAM) Architecture, Part II, Functional Modelling Manual (IDEF0)*, document AFWAL-TR-81-4023, Air Force Material Laboratory, Wright-Patterson AFB, Ohio 45433, 1981, vol. 14.
- [54] TSIA. *Overview on Taiwan Semiconductor Industry*. Accessed: Dec. 9, 2021. [Online]. Available: <https://www.tsia.org.tw/EN/PubliOverview?nodeID=60>
- [55] M. A. V. Borges and L. M. Vieira, "Brazil moving up in the semiconductor global chain," *J. Oper. Supply Chain Manage.*, vol. 7, no. 1, pp. 68–84, Jul. 2014.
- [56] C.-F. Chien, H. Ehm, J. Fowler, and L. Mönch, "Modeling and analysis of semiconductor supply chains (Dagstuhl Seminar 16062)," *Dagstuhl Rep.*, vol. 6, no. 2, pp. 28–64, 2016.
- [57] 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," *Prod. Plan. Control*, vol. 32, no. 10, pp. 829–844, 2021.
- [58] McKinsey. *McKinsey on Semiconductor*. Accessed: Dec. 9, 2021. [Online]. Available: https://www.mckinsey.com/~media/McKinsey/Industries/Semiconductors/Our%20Insights/McKinsey%20on%20Semiconductors%20Issue%207/McK_Semiconductors_Oct2019-Full%20Book-V12-RGB.ashx
- [59] B. Oskin. *Japan Earthquake and Tsunami of 2011: Facts and Information*. Accessed: Dec. 9, 2021. [Online]. Available: <https://www.livescience.com/39110-japan-2011-earthquake-tsunami-facts.html>
- [60] M. Kazama and T. Noda, "Damage statistics (summary of the 2011 off the Pacific coast of Tohoku earthquake damage)," *Soils Found.*, vol. 52, no. 5, pp. 780–792, Oct. 2012.
- [61] TCWB. *Earthquakes: Earthquake Reports*. Accessed: Dec. 9, 2021. [Online]. Available: <https://scweb.cwb.gov.tw/en-us/earthquake/data>
- [62] S. Aggarwal and M. K. Srivastava, *Nissan: Recovering Supply Chain Operation, Management Development Institute*. London, U.K.: Ivey Publishing, 2016.



DAH-CHUAN GONG received the Ph.D. degree from the the Department of Industrial and Manufacturing Engineering, Georgia Institute of Technology, USA, in 1991. He is the Dean and a Professor of industrial and business management with the Management College, Chang Gung University, Taiwan. His teaching and research interests include the sustainable and resilient supply chain management, global logistics, applied operations research, and production-inventory systems analysis.



T. C. HOU received the Ph.D. degree from the Department of Industrial and Systems Engineering, Chung Yuan Christian University, Taiwan. He has a experience/service of 27 years in semiconductor manufacturing service company. His research interests include the manufacturing management in hi-tech industries, technology and operations management, computational intelligence in production systems, and lean manufacturing.



PHUONG HOANG received the M.S. degree in industrial and business management from Chang Gung University, in 2018. He has experience working in supply chain risk management.



BRETT PETERS received the B.S.I.E. degree from the University of Arkansas and the M.S.I.E. and Ph.D. degrees from the Georgia Institute of Technology. He is the Dean and a Professor with the Department of Industrial and Manufacturing Engineering, College of Engineering and Applied Science, University of Wisconsin-Milwaukee. His specialization is in logistics, both networks design and configuration and layout and operations within the facility. He served ten years on the College-Industry Council on Material Handling Education, including a term as the President and a Co-Organizer of the International Material Handling Research Colloquium, from 2000 to 2008. He has previous faculty experience at Texas A&M University, and in 2010, he was named as a fellow of the Institute of Industrial Engineers.



PING-SHUN CHEN received the Ph.D. degree from the Department of Industrial and Systems Engineering, Texas A&M University, USA. He is currently a Professor with the Department of Industrial and Systems Engineering, Chung Yuan Christian University, Taiwan. His research interests include supply chain management, systems simulation, and healthcare simulation applications.

...