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## Building supply chain resilience with digitalization

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**ADB Working Paper Series**

**BUILDING SUPPLY CHAIN  
RESILIENCE WITH DIGITALIZATION**

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**Abstract**

How resilient is your supply chain? The fallout from the COVID-19 pandemic laid bare the vulnerability of global supply chains. One of the main business challenges that firms faced was the lack of end-to-end supply chain visibility, which impacts critical operational decisions. If firms are unable to see what is happening in their supply chains, they will not be able to manage them well. In the aftermath of the pandemic, firms have been incorporating the lessons learnt from the pandemic to reconfigure supply chains and increase visibility and responsiveness to withstand future unanticipated disruptions as well as predictable events such as adverse weather or logistics delays. This paper aims to unpack how digitalization can support supply chain resilience and agility. The key questions are: a) What does it take to become more resilient? b) How can digital technologies play a part in providing greater certainty and flexibility to improve supply chain resilience? and c) How should firms go about implementing digital transformation? This paper discusses and explains the various dimensions, phases, and strategies of supply chain resilience. Resilience is understood as a function of a firm's capability to have a conscious awareness of complex interconnected environments and the reconciling capacity to swiftly manage key vulnerabilities. Hence, increased end-to-end visibility of the supply chains using advanced technology and digitalization is vital for firms to pick up early signals of uncertainties, thereby gaining sufficient time to orchestrate operations and resources to withstand disruptions. However, supply chain visibility is not about a collection of digital tools. The research reveals that the building blocks of digitalization capabilities are a triangle of interconnected value levers comprised of a digital workforce, digital backbone, and digital twin. The paper concludes with recommendations for policymakers on how to best help firms realize their digital potential to boost supply chain resilience.

**Keywords:** digitalization, supply chain resilience, capabilities, responsiveness

**JEL Classification:** M11

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## 1. INTRODUCTION

Today's supply chains are overly global and complex with multiple interdependent echelons and hidden pain points. Yet even without a full spectrum understanding of a firm's supply chain, managers are still capable of "firefighting" and fixing most of the small-scale, unpredictable supply chain issues. But the scale of the COVID-19 pandemic, the ongoing United States–People's Republic of China trade decoupling, and the Russian invasion of Ukraine have disrupted global trade relations and supply chains. Many studies (Ambulkar, Blackhurst, and Grawe 2015; Ali and Golgeci 2019; Carissimi et al. 2022) have pointed out that firms need to enhance the resilience of their supply chains (SCs) to quickly recover from disruptions. This increased supply chain flexibility will better equip firms to withstand unanticipated disruptions, such as a global pandemic, as well as predictable events, such as adverse weather or logistics delays.

Thus, supply chain resilience is at the top of the agenda for firms as well as for supply chain researchers. But what is supply chain resilience? In the literature, there is no clear agreement on a definition of supply chain resilience. Holling's (1996) seminal work on the engineering versus ecological perspectives of resilience laid the foundation for the current supply chain resilience debates. Some of the leading researchers that are taking the engineering perspective in defining resilience are: Rice and Caniato (2003); Christopher and Peck (2004); and Sheffi (2005). Table 1 summarizes the definitions of supply chain resilience from various authors. The core notion of the engineering perspective of resilience is recovering speed and costs. In contrast to this rather 'static' engineering perspective, the evolutionary school of thought argues that firms' supply chains are capable of learning from disruptive events and developing new capabilities to withstand future uncertainties (Hamel and Valikangas 2003; Seville, 2008; Tukamuhabwa et al. 2015). The foundation of this school is adaptive capabilities to accommodate future uncertainties and to emerge stronger after the disturbance (see Table 1).

**Table 1: Summary of the Supply Chain Resilience Definitions**

	<b>Authors</b>	<b>Supply Chain Resilience Definitions</b>
Engineering	Rice and Caniato (2003)	The ability to build a secure supply chain to bounce back from any disruptions. Luck plays no part in the equation.
	Christopher and Peck (2004)	The ability of a system to return to its original state or move to a new or more desirable state after being disturbed.
	Sheffi (2005)	The ability of the supply chain to return to a normal performance level (i.e., production, services, and fill rate) and the speed at which it can do so—after a disruption.
Evolutionary	Hamel and Valikangas (2003)	The ability to anticipate and adapt to change as well as dynamically reinvent supply chain business models as circumstances change. Having the capacity to change even before the cause for change becomes obvious.
	Seville (2008)	The ability to develop the capacity to seize the opportunities that arise from a crisis to build a supply chain that is stronger and better than before.
	Tukamuhabwa et al. (2015)	The ability to develop the adaptive capabilities to make a timely and cost-effective recovery and, therefore, progress to a post-disruption state of operations—a better state than prior to the disruption.

Source: Kim Hua Tan.

The supply chain resilience effort is a complex and challenging journey that will continue through the years. A high level of supply chain resilience can help firms to more effectively prepare for, respond to, and recover from disruptions (Tukamuhabwa et al. 2015; Scholten, Stevenson, and Van Donk 2019; Zhang, Liu, and Godsell 2021). Most of the existing studies argue that supply chain resilience covers pre-disruption, disruption, and post-disruption (Kochan and Nowicki 2018; Zouari, Ruel, and Viale 2021). The three most widely acknowledged supply chain resilience dimensions are Readiness, Responsiveness, and Recovery. These dimensions are also widely acknowledged as the 3Rs of supply chain resilience (see Figure 1). The Readiness dimension refers to the proactive preparation in anticipation of possible disruptions. Examples include planning for alternative suppliers and creating and testing possible disruption scenarios to mitigate labor, manufacturing, and delivery disruptions. The Responsiveness dimension refers to a range and volume of adaptation in order to mitigate the magnitude of disruptions. Examples include intervention in scheduling and temporary workforce arrangements to ramp production up or down during or immediately after disruptions. The focus will be to ensure the continuity of supply chain operations. In the aftermath of disruption. The Recovery dimension refers to how firms could rapidly recover from disruption and achieve new growth. Examples include how firms coordinate the processes of source, make, and delivery operations and restore them to pre-disruption performance levels.

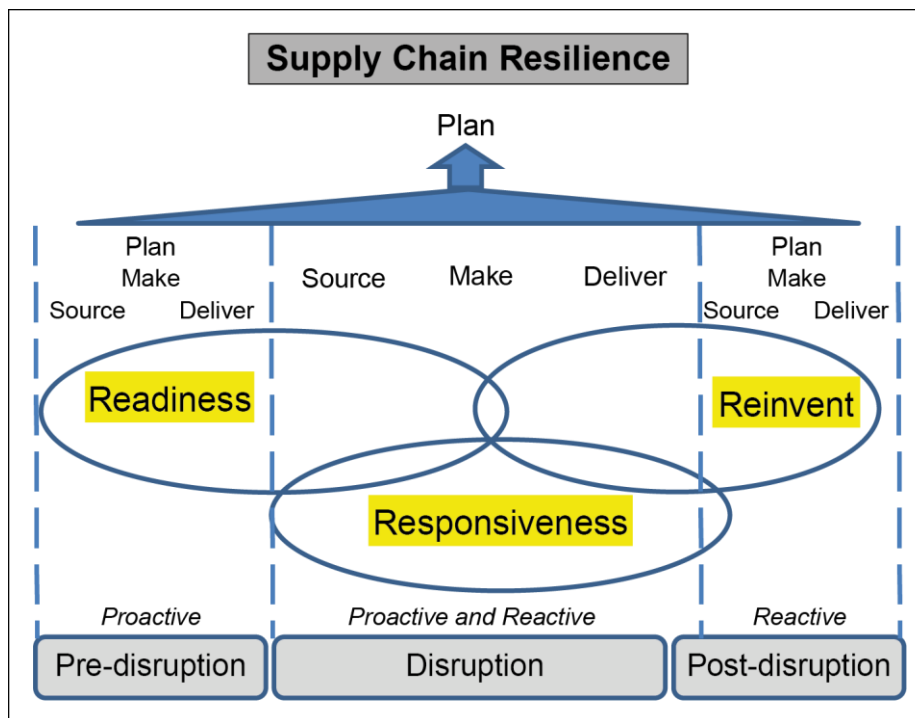
However, given the current competitive business climate, regaining pre-disruption performance may no longer be enough. Incremental adjustments to existing supply chain operations may not deliver a revitalization that is fit to cope with any future unforeseen disruptions or to achieve the advantage needed to effectively compete in the new normal. Firms should also capitalize on the disruption to make a fundamental change in strategy and assets to improve supply chain operational resilience and capabilities. This would help firms to gain new competitive advantages. Supply chain resilience should not only provide consistency for short-term recovery action but also identify new opportunities for repurposing supply chain configurations. In the literature, "Reinvention" implies a significant stretch for a firm's current capabilities and resources. Building on the disruption lessons, firms should learn how to be more creative while making use of existing resources to systematically build new post-disruption advantages, for example, the capabilities to repurpose supply chains and respond quickly and accurately to fast-changing customer demands and market needs. For instance, during the COVID-19 lockdown in early 2020, the Digipas group of Indonesia was able to repurpose its supply chains and production facilities to rapidly ramp up a new product, namely an intelligent face mask to meet new market demand. As such, "Reinvention" is a more appropriate dimension of supply chain resilience than "Recovery."

Two broad sets of strategies are available to firms for the development of resilience across the three phases: pre-disruption (proactive); disruption (proactive and reactive); and post-disruption (reactive). However, the boundaries between proactive and reactive strategies are not clearly defined in the literature. Broadly speaking, proactive strategies involve the pre-disruption and disruption phases in which pre-planning is carried out so that a minimum level of adaptation in supply chain operations is required. The main part of a proactive strategy is to monitor component availability. Key practices include demand forecasting and emergency planning; using real-time data to gain better supply chain visibility; and establishing multiple sourcing and buffer management. Reactive strategies normally involve the disruption and post-disruption phases in which flexibility is vital for firms to adapt themselves to fast-changing supply chain environments. For example, to quickly find alternative components or suppliers to substitute for component shortages; or to rapidly repurpose operations to ramp up the

production volume of new products to meet new market needs. Figure 1 illustrates the 3Rs, that is, three phases, and the two supply chain resilience strategies.

Regarding metrics for supply chain resilience, the two most common measures are time to survive and time to recover. Time to survive normally refers to the amount of time required for firms to regain supply chain operations after a disruption. For example, the time taken to secure approval from authorities and to restart factory operations after a lockdown. The time to recover metric is mainly composed of the time to recover all unfulfilled orders and incomplete work and to resume normal operational capacity. Recently, Jabil Caltabiano (2022) introduced a third metric, that is, time to thrive, which measures the states of the firm pre-and post-disruption.

**Figure 1: 3Rs, Three Phases and Strategies of Supply Chain Resilience**



Source: Kim Hua Tan.

This paper investigates how firms could build supply chain resilience with digitalization. It addresses three important research questions: a) What does it take to become more resilient?; b) How can digital technologies play a part in providing greater certainty and flexibility to improve supply chain resilience?; and c) How should firms go about implementing digital transformation? These issues have considerable significance for supply chain management and policymakers in developed and developing countries. To address the research questions, a neo-systematic literature review of digitalization and supply chain resilience literature in the last 15 years (2007–2022) was conducted. The systematic literature review (SLR) is a robust evidence-based review approach in supply chain management research (Tranfield et al. 2003). Through systematic identification, analysis, and interpretation of relevant publications, the SLR allows researchers to map out and have a critical overview of the existing territory of knowledge and the existence of any gaps.



The review started with identifying and selecting the most relevant “resilience,” “visibility,” “transparency,” “COVID-19 resilience,” and “digitalization” keywords in titles, abstracts, and full texts from journal articles in four leading business management databases, namely ScienceDirect, ABI/Inform, Business Source Premier, and Emerald. After screening more than 560 relevant abstracts, 34 articles were deemed to be suitable. These outputs were screened for relevance to ensure that only publications that specifically discussed supply chain resilience, visibility, and digitalization were analyzed. Not surprisingly, most of these articles were from 2020 onwards in response to the COVID-19 disruptions. The process was then repeated in the Google search engine to find relevant articles, books, blogs, and news. Although the review process does not guarantee that all the related supply chain resilience articles are covered, the author believes this method has collected a critical mass of representative supply chain resilience materials that serve as inputs for this research paper.

The paper begins with a discussion of supply chain resilience dimensions, phases, and strategies. Next, the chokepoints and vulnerabilities in the supply chain are reviewed, and the advancement of technology and digitalization in enhancing operations visibility is examined. Section 4 discusses the key building blocks of digitalization capabilities. The paper concludes with recommendations for practitioners and policymakers on how best to help firms realize their digital potential to boost supply chain resilience.

## **2. UNDERSTANDING CHOKEPOINTS AND VULNERABILITIES IN SUPPLY CHAIN**

How can you achieve supply chain resilience or where should you begin? In the art of war, one of the famous Sun Tzu quotes is “if you know the enemy and know yourself, you can fight a hundred battles without disaster.” Accordingly, understanding a firm’s existing supply chain chokepoints and vulnerabilities are the key step in the supply chain resilience journey. At times of unforeseen events, the weakest links in the supply chain will be at their most vulnerable and at risk of sending ripples along the whole supply chain. Thus, firms should evaluate their supply chains to identify critical raw materials or components at risk from shortages or price fluctuations. Firms should also identify which processes, transportation, or facilities could be the tipping point that causes failure in the supply chains.

Although there is no clear definition in the literature, the term chokepoint or pain point generally refers to a process point in an operation that can jeopardize the entire supply chain operation if it fails (Alicke and Kwan 2021). In normal times, today’s global supply chains are designed to function with high dependability and reliability at the lowest cost. Nonetheless, many international aspects are uncontrollable, such as trade wars, changing tariffs, and shipping, and add to firms’ supply chains risk exposure. Therefore, an unanticipated, sudden disturbance may deviate from many interconnected planned operations and turn a lean and well-managed supply chain upside down. For example, the lack of delivery drivers during the COVID-19 pandemic as a result of restrictions and lockdowns was a chokepoint for many logistics firms. Chokepoints are thus vulnerabilities in the supply chain, and they should be identified, managed, and eliminated over time. Given the complexity and globalized nature of today’s supply chain operations, there are some inherent chokepoints that are inevitable. For example, long delivery lead times, a single source or dependency on commodities from a single region. Consequently, firms need to be aware of where the vulnerabilities exist and how those chokepoints can fail in the supply chains.

The three main sources of uncertainty in supply chains are suppliers, production, and customers. It is essential to carefully examine each source to understand the supply chain-wide impact of the uncertainties and the likely impact on customer service. Supply chain vulnerabilities tend to manifest in four key areas: a) raw materials and supply networks; b) transportation and logistics systems; c) production planning and operations; and d) customer fulfillment.

Unforeseen disruptions will affect all echelons in the supply chains, including overseas suppliers. Without raw materials or components, firms may have to stop production and will be unable to meet customer deadlines. Shortages of materials will also trigger more holdups and unpredictability and amplify the bullwhip effects – meaning that a small variation in downstream customer demand will be amplified as orders move further up the supply chain (Lee, Padmanabhan, and Whang 2015). Single-source components or suppliers concentrated in a single region are another obvious vulnerability. For example, in early 2020, one firm in Indonesia classified as a small- and medium-sized enterprise (SME) realized that all the tier one and tier two key component suppliers were in the same country and facing serious COVID-19 lockdown measures. Hence, firms should consider multi-sourcing and, if possible, use various suppliers from different regions. If multi-sourcing is not possible, then firms should build relationships with suppliers to share information and receive early warning of potential shortages, which can improve supply chain visibility.

Today's supply chains depend on the tight integration of networks of operators and service providers in the delivery of goods and services, from the raw materials stage to the final products to customers (Chowdhury, Quaddus, and Agarwal 2019). Supply chains involve intricately linked transportation, warehousing, and last-mile delivery logistics systems (Davis 1993). Often, materials movements cross borders and cut across various regions and are always vulnerable to uncertainties and extreme weather events. For example, in the electronics industry, the manufacture of a smartphone will involve multiple supplier shipments with differing regularity to manufacturing sites in various regions of the world. At these sites, components, subassemblies, and final assembly operations of the final products are undertaken with complicated production lines and uncertain processes. The products are then shipped to distributors, wholesalers, or final customers. The logistics are further complicated by the various options available for transportation: ships, planes, trucks, delivery drones, or trains. The uncertainties and vulnerabilities existing in such complex supply chain networks can easily be imagined. Higher fuel prices along with shortages of shipping containers, truck drivers, or warehouse pick-and-pack operators are the lingering infrastructure pain points. Some researchers have pointed out that logistic clusters, that is, co-location of value-added logistics services at scale, could mitigate some of the transportation and logistics vulnerabilities. Information sharing is vital for supply chain coordination (Park, Hong, and Roh 2015; Scholten and Schilder 2015; Sa et al. 2019). In this way, real-time information on delivery can provide better visibility and buffer time for firms to explore alternative delivery.

To improve efficiency and to minimize the supply and demand mismatch, firms typically spend significant amounts of effort on medium- to long-term production planning and resource allocation. However, a supply shortage, power failure, machine breakdown or worker unavailability can cause a deviation from the initial production plan and cause disruption throughout the whole supply chain. Though some of these factors are external, such as a power failure, pandemic worker restriction, or changes in demand, firms should nonetheless seek to have better end–end supply chain visibility to prepare for the unexpected. This is to ensure that the recovery plan can cope with the changed environment brought about by the disruptions as well as meet the initially promised

customer delivery. In brief, the level of a firm's resilience is also crucially affected by the capabilities of its customers and suppliers to anticipate and respond to disruption.

The COVID-19 pandemic has changed consumer purchasing behavior. The sudden increase of online shopping has made many firms' conventional warehousing and fulfillment strategies irrelevant and unable to meet customer delivery expectations. Fulfillment disruptions are not new, but today's supply chains are being stressed in multiple ways all at once. No firms can accurately predict the future, but they can take actions to address the fulfillment vulnerability and meet customer expectations. Firms could improve fulfillment networks by diversifying logistics service providers and with better inventory management; that is, the right inventory at the right location at the right time. Moreover, better management of customer expectations is crucial. Unfulfilled orders and delays are not good ways to impress customers. Thus, providing real-time updates on changes and delays to customers is a must. Tukamuhabwa et al. (2015) argued that the adoption of relevant digital and information technologies can boost the flexibility, visibility, collaboration, and velocity of operations, which are all critical for supply chain resilience.

### **3. LEVERAGING DIGITALIZATION FOR SUPPLY CHAIN RESILIENCE**

In the aftermath of the COVID-19 pandemic, firms learned that they should reduce complexities by shortening and strengthening their supply chains to face future uncertainties. Increased end-to-end visibility of the supply chains is vital for firms to pick up early signals of uncertainties, allowing themselves sufficient time to orchestrate operations and resources to withstand disruptions. Today's advanced technology and digitalization are ready to make supply chains more transparent, thereby providing firms with many capabilities to cope and even emerge stronger after disruptions (Pu et al. 2021; Cui et al. 2022; Gandhi 2022). Savvy managers are quick to tap the values provided by advanced technologies to make their end-to-end supply chain more resilient and cost efficient. Advanced technologies (such as artificial intelligence, robots, virtual realities, cloud computing, blockchains, and 3D printers) are making it possible for firms to monitor operations in real-time, adjust inventory and supply sources, as well as make early interventions. In addition, they are helping firms to streamline complex supply chain operations and reduce the time needed to train workers to be ready for repurposing supply chain operations. Firms are riding on the wave of digital transformation to gain many benefits in the supply chains, including:

*Transparency and Predictability.* Firms need time to align resources and capabilities to better deal with uncertainties (Ferdows and De Meyer 1990). To do so, firms need real-time data, not just on the internal operations but also on the upstream and downstream of the supply chains. Technologies such as artificial intelligence (AI), blockchain, and the Internet of Things (IoT) allow firms to digitalize their supply chain operations so that data can be shared in real time, more frequently, and captured for further modeling and analysis in order to identify trends and network dependencies. With better visibility, firms have a complete real-time view of the supply chain inventory and status and can take proactive risk mitigation measures as needed. For example, firms can adjust inventory decisions in anticipation of potential disruptions or changes in market needs. Gap, a leading fashion retailer, is using AI and machine-learning tools to better allocate its inventory; that is, to predict demand for styles, colors, and sizes as well as forecasting ahead of and during seasons, considering factors such as the weather to anticipate market needs (Broughton 2021). In addition, firms could use

advanced algorithms and simulations to develop a “digital twin” of their supply chain operations in a virtual world. A supply chain digital twin is a digital replica of the physical supply chains (including management processes). Firms could use the supply chain digital twin to test scenarios, model different flows, identify the chokepoints, identify optimal worker–machinery interactions, and understand how disruptions could spread through the supply chains. In addition, data collected from the digitalized operations could be used to train predictive models to obtain more accurate forecasting.

*Repurpose Production and Ramp Up of Volume.* During the COVID-19 crisis, many firms experienced either a sudden drop or increase in market demand. For some firms, almost overnight, their main products were no longer in demand in the market. For example, a digital luggage lock manufacturer experienced almost zero sales during the two years of the global lockdown, whereas a personal protection equipment (PPE) firm saw a sudden, big surge in demand overnight. In addition, governments around the world strongly encouraged firms to repurpose their supply chains to address the shortages of critical items, such as PPEs and ventilators. Hence, firms must develop the capability to repurpose their manufacturing to keep supply chains working during disruptions. Modeling tools, cloud computing, and digital twins make it possible for firms to repurpose manufacturing operations for those goods that are in high demand. Digital technologies, such as 3D printing (or additive manufacturing), enable rapid prototyping and make it possible for firms to affordably produce a broad range of components and products in a short period of time (see Table 2). Many firms are not able to respond quickly to any disruptions or sudden changes in demand because of long lead times (days or weeks) to order and transform raw materials into finished goods. Digitalization of supply chain operations will make it possible for firms to quickly respond to: a) pivot to manufacture different products to meet market needs; and b) to ramp up production volume to meet high demand.

*Remote Working and Training Flexibility.* An obvious downside of social distancing for firms was the shutdown of factory operations. Today, advances in 5G technologies, virtual meetings, and digitalization of working processes allow hybrid/remote working as well as flexibility in where and when people work. Remote working also helped firms to comply with the COVID-19 social distancing guidelines. Virtual reality and augmented reality are powerful virtual training tools that provide workers with immersive learning experiences that allow them to grow knowledge and develop new operational know-how skills. Digital training tools provide flexibility, allowing firms to remotely train their workers in combination with the ability to test the workers’ newly gained skills and knowledge at any time. Table 2 summarizes some of the key digital technologies and how they could be used to support supply chain resilience.

**Table 2: Key Digital Technologies and Their Possible Use to Support SC Resilience**

Digital Technologies	Applications	Supply Chain Resilience		
		Transparency and Predictability	Repurpose Production and Ramp Up Volume	Remote Working and Training Flexibility
Artificial intelligent (AI)	Advanced algorithms and machine learning can process large volumes of data and solve problems at higher levels of speed and accuracy. AI can support accurate demand prediction and facilitate smart decision making in supply chains.	✓	✓	
Internet of Things (IoT)	A system of connected, smart sensors that could collect, share, and analyze real-time data. Widely used in inventory management, maintenance, transportation, and production.	✓	✓	
Blockchain	A digital ledger that provides digital evidence of what is occurring in the supply chain. The shared ledger facilitated “trust” among network members and cut down lead times and paperwork.	✓	✓	
Digital twin	Living replica of supply chain processes and systems. Based on real-time data, firms can gain end-to-end supply chain visibility and test various supply chain disruption scenarios.	✓	✓	✓
3D printing	3D printing (additive manufacturing) makes it possible for firms to manufacture components in factories, hence shortening manufacturing lead times and reducing reliance on overseas suppliers.		✓	
Robotics	New advancement in Cobots (robots that directly interact with workers) that boost productivity and support rapid production ramp up. Robots and automation allow firms to operate longer hours without health and safety constraints.		✓	✓
Virtual reality/ Augmented reality	Virtual reality (VR) and augmented reality (AR) allow firms to rapidly develop digital training packages and simulate supply chain operations to train or reskill workers. Self-isolated workers also have the flexibility to train and learn new skills remotely.		✓	✓

Source: Kim Hua Tan.

#### 4. BUILDING DIGITALIZATION CAPABILITIES FOR SUPPLY CHAIN RESILIENCE

COVID-19 has shown that firms with poor end-to-end visibility supply chains are vulnerable to disruptions. Many studies have indicated that digitalization of supply chains using advanced technologies can improve supply chain visibility and resilience (Zouari, Ruel, and Viale 2020; Kittipanya-Ngam and Tan 2020; Iftikhar et al. 2022). But how can firms build supply chain resilience with digitalization, and where should they start? There are many general-purpose frameworks available in the literature to provide firms with an overview of digital technologies and challenges in the supply chain digitalization process. Some of these frameworks allow firms to assess their digital maturity, but they are general purpose and not cut out for the supply chain resilience

task. To develop a sustainable digitalization capability for supply chain resilience, a robust digital backbone, a digital twin, and an enhanced digital workforce are some of the key value levers that firms must pull. Figure 2 illustrates the proposed building blocks of supply chain digitalization capabilities for supply chain resilience. The triangle constitutes the boundary of the supply chain digitalization, enclosing the capabilities on which it relies. The arrows on the triangle boundary stipulate the coordination being applied. The triangular shape is convenient for representing hierarchic structures and has no other significance.

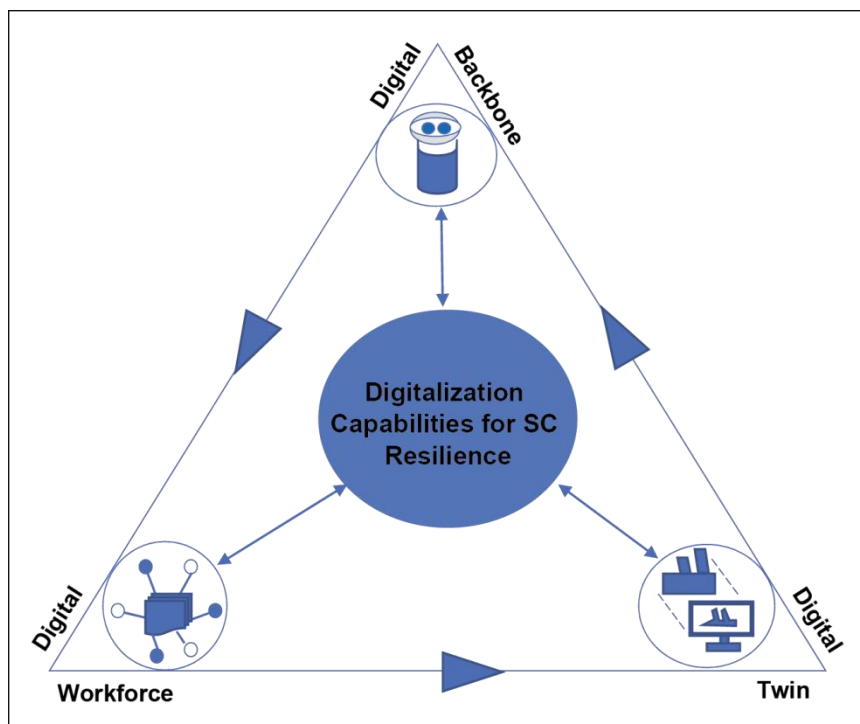
## 4.1 Digital Backbone

In order to achieve end-to-end supply chain visibility, firms need to capture vast amounts of real-time data (inventory, delivery, weather, production, worker availability, sales, etc.) all along their supply chains (Zhan and Tan 2017). This includes data collected from different sources, such as: radio frequency identification (RFID) tags; global positioning systems (GPS); loyalty cards and Point of Sale (POS) transactions; and data emitted by social media feeds and equipment sensors. From the collected data, firms could utilize artificial intelligence, machine learning, and other game-changing data analytics to gain better insight into supply chain operations and provide better value-added services to customers (Tan et al. 2015; Tan et al. 2017). For example, data collected on suppliers' on-time deliveries, average lateness, and degree of inconsistency are valuable to firms in making inventory decisions, such as how much extra stock needs to be held, where it should be held, and when to hold it to keep the supply chain running reliably.

Hence, a supply chain "digital backbone" is needed to coordinate the seamless collection, sharing, and integration of data along the supply chains. Firms need to establish the key digital technologies that underpin the entire supply chain ecosystem so that sensors in different domains and platforms can connect to/communicate with each other and so that firms can have access to data in real time. The digital backbone is a secure, firm-specific digital architecture that is comprised of smart platforms, cloud-based applications, automation, and lean processes. Firms need the digital backbone to deliver real-time supply chain visibility to mitigate uncertainties. Apart from linking the technologies and data collection sensors, a digital backbone should also drive real-time interoperability across domains and platforms of the supply chain stakeholders (suppliers, partners, logistic providers, and customers).

Developing one's own cloud and platform systems may be costly and time consuming. Therefore, firms could leverage and take advantage of existing innovative Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS) solutions available in the market. When evaluating the option, firms need to assess the cost and speed of deployment as well as the pros and cons of public and private cloud and data centers.

**Figure 2: Building Blocks of Digitalization Capabilities for Supply Chain Resilience**



Source: Kim Hua Tan.

## 4.2 Digital Twin

Considering the fast-changing business landscape and frequency of disruptions, the old way of theoretical modeling and simulation to enhance supply chain resilience is no longer adequate. When complex, interrelated events interact with one another, the existing model-based systems lack closed-loop information control capabilities to cater to the uncertainty during disruption. To strengthen the supply chain resilience in a proactive manner, a digital supply chain twin, which refers to a digital replica of the physical supply chain, is required (Ivanov and Dolgui 2020). The information that physical supply chains provide, such as transportation status, production level, customer demand, and inventory level, can be collected in real time for firms to monitor and make decisions. A digital twin enables the simulation of a supply chain to evaluate the disruption propagation and its impact. Via the digital twin, firms can model and predict the relative impact of different sources of uncertainties in the supply chains as well as measure the indirect effect of uncertainty on downstream or upstream echelons in the supply chain. As a result, the recovery policy, remedy measures, and contingency plans to address the identified disruptive events can be proactively formulated. Firms could also examine and understand the possible impact of adjusting inventory parameters across supply chains and the implication on costs and customer service.

The data sources enabled by the digital backbone need to be seamlessly integrated and updated to the supply chain digital twin in real time. In addition to supply chains, there are digital twins for products and infrastructure. For example, a product digital twin can help firms reduce development time and, hence, time to market as well as to improve product quality. Firms can do many rapid iterations and optimizations

of product designs and manufacturing processes using the product digital twin to eliminate potential design flaws.

The full value of the supply chain digital twin relies heavily on the amount of high-quality data from multiple sources that the twin would require. In addition, it will often require a highly skilled workforce with strong simulation and analytics capabilities.

### **4.3 Digital Workforce**

Cloud platforms and collections of Software-as-a-Service-based team productivity applications are the backbone and foundation for supply chain digital transformation. Needless to say, the knowledge and skills of a firms' workers in the areas of intelligence, machine learning, data analytics, and process automation will be critical in continuing their supply chain digital transformation. Therefore, the upskilling of workers' digital capabilities for a digital age is essential to supply chain resilience. Digital technologies and workers' dexterity and behaviors toward them are key for successful digital transformation. Moreover, as the digital technologies landscape is rapidly changing, firms need to constantly develop reskill strategies to have the right capability, size, and shape of the worker digital dexterity.

There is no one-size-fits-all approach to upskill workers' digital dexterity. Firms can grow talent internally or via an external pipeline using apprenticeships and graduate schemes. Firms can rely on external talent to fill immediate digital capability gaps, but they also need to establish a roadmap for how to best upskill the existing workforce. One thing is clear: high workers' digital dexterity will increase the firms' digital transformation. Accordingly, sound talent management and incentive schemes would be required.

## **5. RECOMMENDATIONS FOR PRACTITIONERS**

Recent COVID-19 pandemic disruptions, the United States–People's Republic of China trade war, and the Russian invasion of Ukraine have all clearly shown the world that lean and agile operations are not enough to help firms withstand uncertainties. A resilient supply chain demands a short and quick response time, time to recover, and time to thrive in all three stages of the disruption. Firms need to develop capabilities to repurpose existing supply chains and invest in technologies. It is necessary for firms to be able to digitally model the propagation of uncertainty up and down the supply chains and to use the outputs of the model to support strategic decision making about supply chain operations. Fortunately, firms could tap into advanced technologies, such as AI, IoT, Blockchain, robotics, VR/AR, and simulation models to transform and gain better end-to-end visibility to achieve supply chain resilience. Supply chain digitalization enables firms to connect and integrate complex operations at multiple levels and to grasp dynamic operations in real time. The time required to detect potential disruption, its scale, the duration of disruption, and the recovery time is key for supply chain resilience and to maintain satisfactory service levels to customers.

The study highlights for supply chain practitioners and policymakers how to develop digital technologies capabilities to strengthen the supply chain resilience to withstand future uncertainties. A framework for digitalization capability development will provide clarity and help firms to identify the coordination needed to achieve resilient growth. Supply chain digitalization enables firms to proactively identify and manage risks, particularly since many of the conventional supply chain risks stem from a lack of collaboration and visibility (Alicke and Swan 2021). Digitalization offers accuracy and



transparency to enhance the overall resilience across all members of the supply chain networks, from raw material suppliers, logistics providers, warehouse operations, and retailers to customers. Good supply chain visibility and assessment enables firms to understand current pain points and vulnerabilities at the supplier level and assess the level of exposure to uncertainties. Supply chain digitalization transformation is key to support the 3Rs of resilience. “Readiness” refers to a firm’s ability to ensure continuity of supply chain operations and quickly recover from external disruptions. “Responsiveness” refers to a firm’s ability to restart the supply chain after complete stops and redesign/reconfigure the supply chain to meet new demands under/after external disasters. “Reinvention” refers to a firm’s ability to quickly and accurately respond to the fast-changing customer demands and market needs. Practitioners could also capitalize on the new digital capabilities to realign supply chain capabilities and develop competitive advantages for the next normal.

Before embarking on the digitization journey, firms need to be aware of the resource requirements and consider existing digital maturity. Several questions should be considered. What cloud-based systems and platforms are required to collect, share, and analyze data seamlessly? How can a firm tap into the real-time data feed to enhance decision making? What degree of upskilling is required to build a digital-enhanced workforce? This study points out the building blocks of capabilities required for building supply chain resilience with digitalization. If developed, these capabilities can provide strong support for firms seeking to efficiently deploy digital solutions to enhance supply chain resilience. Implicit in the architecture is the assumption that firms have the means and resources to build the capabilities.

A sound and robust supply chain transformation draws heavily on a clear, prioritized set of cloud-based digital platforms and solution requirements in terms of the criticality of the supply chain operations issues that need to be addressed. Firms need to ensure that the bolt-on systems have high connectivity with existing operating systems and that both the firm internal and external supply chain members have instant, secure, and private access to this data. To gain a better competitive advantage, firms need a digital architecture that serves as the backbone connecting their core assets and operations that enable an integrated and seamless way of working. Firms should envision the connected, digitalized supply chain operations as a living organism that could respond to uncertainties and disruptions in real time, without sacrificing high quality products and innovative services for customers. With seamless interoperability of the connected platforms and systems, firms can tap into the data to develop a model of each specific supply chain process and system to monitor performance in real time. In other words, the digital twin is a living model of the supply chain physical asset and system. Through the up to date and analytical insights gained from the digital twin, firms could make timely decisions and interventions to maximize performance in terms of product quality, cost, responsiveness, and service delivery. Nonetheless, investing in digitalization is not enough; firms also need to enhance workers’ digital capabilities as part of building a digitalized supply chain. An enhanced digital workforce is the fuel for digital transformation. To do this, firms need to keep pace with the rapidly evolving digital technologies and to anticipate the skills that will be needed in the future.

The proposed digital backbone, twin, and workforce triangle do not comprise a supply chain resilience solution but rather a navigation towards a proposed digitalization end-to-end operation for better visibility. The building block architecture of capabilities is general and should be applicable to practitioners keen to develop digital supply chain solutions. The architecture enables practitioners to decompose firm-level capabilities to be as detailed or focused as required. For example, the digital backbone that underpins a production line, the digital twin that populates it, and the workforce that

manages it feeds and modifies it and so on. But bear in mind that each of the building blocks can trigger a paradigm shift for supply chains. Hence, practitioners may consider a fundamental change to the supply chain configuration and order a penetration/decoupling point to best exploit the potential of integrated digital technologies. In addition, introducing resilience metrics into KPIs helps firms ensure supply chain decisions are made to balance cost, efficiency, and performance. Given that supply chain disruptions are fast changing, firms should conduct regular stress tests and reviews to ensure the resilience KPIs remain appropriate. Lastly, firms will also need a flexible, robust management control system and an agile organizational structure with a dedicated team to proactively respond to challenges faced in the fast-changing digitalization journey.

## **5.1 Recommendations for Policymakers**

The digital transformation is driving swift changes in the global supply chain at an unprecedented scale. At a time of rapid change and high uncertainty, policymakers in developing Asia and the Pacific need to provide the best support and resources to allow firms to ride the wave of digitalization. This is to build up supply chain resilience to gain competitive advantages. Firms need support and guidance on what digital technologies are being adopted and how and where to acquire them. They also need conviction that their supply chain security is robust and protected before data is shared with members of the supply chain.

The following recommendations on digital backbone and digital talent are to help policymakers better identify vulnerability, anticipate disruptive changes, develop a digital workforce, promote digital security, and develop innovative policies to support firms' digitalization.

### **5.1.1 Digital Backbone**

Excellent telecommunications and digital infrastructures are the backbone of any successful digital transformation and are fundamental to a thriving digital economy. The government's digital strategy and masterplan should ensure that fundamental telecommunications and digital infrastructures are sound with good broadband coverage both in urban and rural areas. Every corner of the country needs to meet the international standard, a secure digital infrastructure so that firms and consumers can access the connectivity they need – at home, office, or transport. Policymakers need to make significant progress in rolling out wireless connectivity and improving coverage.

Digital data security policy should not only narrowly concentrate on national security but also direct more attention to the economic and social dimensions of digital security. Outstanding connectivity should be coupled with sound data protection laws. Policymakers in developing Asia and the Pacific should ensure local data protection laws are compatible with the regional and international standards of data protection. To do this, policymakers should promote the digital security strategy via relevant ministries at the government level.

Policymakers should bring forward or reform legislation to safeguard the responsible use of personal data – which is key for global competition – to provide firms with the clarity and confidence they need in the supply chain digitalization journey. Another key point is that policymakers in developing Asia and the Pacific should seek international compliance and agreements to facilitate the free flow of data with trust and avoid data localization if possible. In other words, a strong and trusted digital economy is the engine for thriving economic growth. This is the reason legislation and laws should

keep pace with digital technology development, continuing to provide firms with the latest tools, knowledge, products, and services to operate safely. Other crucial steps in delivering the secure digital backbone foundation are the inclusion of more publicity and materials to raise awareness as well as instilling a positive digital data security culture among users.

In addition to speeding up digitalization, solid telecommunications and a digital backbone with safe digital data could also add value in the following areas:

- Promote electronic commerce – Although electronic commerce exploded during the COVID-19 disruption, policymakers should do more to promote the growth of electronic commerce and to increase national capacity for firms to implement it.
- Ensure service delivery quality – An integrated digitalization can enable essential government services to be delivered in a responsive and people-centered manner and better accommodate the needs and expectations of firms.
- Protect firms from fraud and data theft – A robust digital data security strategy will ensure sensitive customer and worker data is protected at its source. Firms are able to provide a world-class trusted digital experience that earns workers' trust and customers' loyalty.

### **5.1.2 Digital Talent**

Policymakers in Asia and the Pacific should be aware that the digital backbone is as much about digital talent as it is about data and security. The rapidly changing world of work practices will require our workers to upskill and learn new digital skills to remain relevant. Hence, successful exploitation of the digital backbone will require firms to transform and embed their workforce with digital skills. As the pace of digitalization is globally gaining momentum, the demand for digital talent is high. Thus, policymakers need to invest in developing and nurturing a digital workforce, offering accessible training opportunities, and a full commitment to equip the workforce with digital competence so that there is a sufficient supply of digitally- and technology-enabled workers at all levels. To unlock the full potential of digitalization and to improve the availability of digital talents, the following recommendations are suggested for the policymakers in Asia and the Pacific:

- Enlarging the digital education channel and occupation pathways. More resources should be invested to strengthen the pipeline of knowledgeable and digitally savvy teachers. This ensures that digital and technology courses are well taught in schools and universities. With the right teaching and training infrastructure, it is possible to improve digital education in schools and increase the number of undergraduates and the digital skills of the next generations to enter the workforce. Policymakers should also ensure that young people are aware of the breadth of digital careers and opportunities. Government websites should be available for them to learn about various digital career information and demonstrate how various pathways of skills, qualifications, and apprenticeships align to an occupation.

- Supporting lifelong learning and continuous improvement. The policymakers should provide various channels (digital bootcamps, skill retraining programs, etc.) for workers to reskill for digital roles in the dynamic job market. Scholarships and bursaries should be made available for workers from underrepresented groups to develop the talent required to support the cutting-edge digital job market. To enhance the learning experience and knowledge acquisition, it is vital for learners to understand and be aware of their digital skills level. Hence, policymakers should work with teachers and practitioners to develop a digital skill framework to effectively identify workers' digital talent levels so that they could be referred to the appropriate level of advanced, intermediate, or foundation digital courses. Policymakers should also explore whether the existing tax mechanism is adequate to incentivize firms to invest in high quality training and continuous improvement. The idea is to bring in firms and universities so that they, too, have vital roles in developing workers' digital skills capabilities.
- Competing for global talent. It is well understood that global talent can improve firms' digital intellectual capital and complement the domestic digital workforce pipeline. Policymakers should streamline processes to enable firms to quickly, easily, and globally attract the best digital talent. For example, the UK government is launching various initiatives, such as the Global Talent Visa and Global Business Mobility, to reform and expand several existing pathways to allow firms greater flexibility in transferring digital skills workers from overseas to the UK via a fast-track pathway (UK Government 2022).
- Cultivating an innovative digital culture. Practitioners can easily explain to policymakers that acquiring digital talent won't be enough. To realize **the full potential** of supply chain digitalization, firms need to foster an agile and innovative culture in which workers could confidently find new ways to capitalize on the digitalization across the supply chain operation and business domains. Hence, policymakers should collaborate with firms to develop initiatives to cultivate an innovative digital culture that encourages creativity and risk taking and disintegrates the barriers to innovation and exploitation.
- Boosting leadership and management capability. A fish rots from the head down. Acute leadership and management capability in the digital era is key for successful digital transformation. Digital talent is not enough without the right leadership to innovate the business model and consider how to adopt and invest in new digital technologies to fuel growth and success. Firms often experience lengthy and difficult processes to integrate new technologies, select the right software or technology platforms, and obtain financing. It is important to note that to maximize the operation's effectiveness, a digitalization process will often lead to organizational restructuring as well. Likewise, policymakers should ensure there are dedicated online support services available to offer free and impartial advice to managers: a) on what technology platforms are best for digitalization; b) guidance on early preparation before placing the order; and c) the type of organizational structure that is suitable for the digital era, control systems, and decision-making processes. A supply chain digitalization mentor scheme will be a good start on addressing the leadership and management challenge in Asia and the Pacific. The UK Help to Grow Management scheme (Help to Grow 2023) is a good example of how to support leadership development with expertise linked to industrial digitalization and resource efficiency.

The process of digitalization of supply chain operations can be costly and time intensive. Hence, the policymakers in Asia and the Pacific should be aware that firms need a steady stream of capital to invest and grow. Enabling the availability of funding and improving access to capital across all stages of the digitalization lifecycle is an essential prerequisite of digitalization. The policymakers in Asia and the Pacific should ensure the availability of capital and a funding ecosystem to support firms in the digitalization journey. The majority of the firms in Asia and the Pacific are small- and medium-sized firms (SMEs). Therefore, these SMEs need access to government business support schemes to expand and invest in digital technologies in order to join the global digital bandwagon. Digitalization is a continuous process, and more scale-up investments will be needed in its later stages. Policymakers should remove obstacles for SMEs to seek overseas investors for investment in digitalization if needed. Moreover, an SME advisory service for supply chain digital adoption should be established to provide much-needed impartial advice on technical, process, and change management expertise.

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