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Redefining Resilience: Integrative Review and Development of an Assessment Tool

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Redefining resilience: Integrative review and development of an assessment tool

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Abstract

The outbreak of the COVID-19 pandemic unleashed supply and demand disruptions, sending shockwaves throughout supply chains in unprecedented ways, which directed, once again, the spotlight on the topic of supply chain resilience. Resilience in operations can shield organizations against disruptions through the implementation of diverse measures. Considering existing definitions of resilience, we propose a new definition that captures three components: degree of impact, duration to recovery, and post-disruption state. As such, resilience is a multi-dimensional measure. More important, we summarize thirty-two diverse aspects of resilience and develop an encompassing assessment tool which categorizes these aspects into several core dimensions of organizations—supply, internal operations, communications, transportation, distribution, financial resources, human resources, and overarching approaches (the latter being a new addition to the standard list of seven business cores). These dimensions are essential levers, and organizations can decide which levers work best for them and integrate them into their operations. While one cannot guarantee resilience, acting along these dimensions can reinforce and enhance performance ahead of future disruptions. Our assessment tool accompanies this paper and can be employed by various stakeholders to assess their degree of resilience and identify areas for action.

1. Introduction

Disruptions affecting supply chains come in different flavors. Disruptions—strikes, theft, congestion, natural disasters and so forth—can have effects ranging from the local to the global, can be brief or long lasting, can impact one part of the organization, or cripple it entirely. The Covid-19 outbreak triggered an overarching discussion on the resilience of supply chains, raising questions on how to assess resilience, and causing many to ruminate and ponder: what is resilience exactly? This necessitates a clear grasp of the meaning of resilience in the context of supply chains. Subsequently, a clear definition can facilitate a comprehensive assessment that diverse stakeholders can apply, ultimately identifying their organisations' vulnerabilities and areas for improvement.

Often, organizations can respond even faced with major disruptions. Back in 2003, when the SARS outbreak was detected, it had an immediate effect on the availability of labor. The outbreak, later declared an epidemic by the World Health Organization (WHO), and its spread, were controlled with lockdown measures in various regions. The effect, in this case, was limited to a short time-period and primarily to a few regions in Asia. Industry has since managed to respond to such short-term breakdown in the supply chain with simple practices relating to inventory management or a shift in operation facilities. Almost a decade later, in 2011, when a tsunami hit Japan, the impacts were limited to the Japanese population and industry, whereas consumer demands in other regions were barely impacted, and supplies were replaced by alternate products until operations of Japanese industry resumed. Recurring, and to some degree predictable, tsunamis and other natural disasters (e.g. earthquakes, hurricanes) trained industry to proactively respond with a pre-mediated shutdown, overstocking inventories to meet demand during operation shutdown periods, and moving operations to alternate facilities with increased capacity.

The outbreak of COVID-19 was initially expected to be contained within a few months and its spread to be limited to China. Industry, as well as consumers, started stockpiling and moved their operations temporarily to alternate facilities when possible. Nevertheless, the virus managed to spread worldwide with the World Health Organization's declaring it a pandemic on 11 March 2020, while wide-ranging supply chain effects were felt everywhere. Of substantial impact was the closure of production facilities and transportation networks, which resulted in disruptions throughout the supply chains. Guan et al. (2020) report the effects of movement restrictions felt in the supply chain downstream, as demand saw dramatic shifts toward basic groceries and pharmaceuticals (including hoarding behavior), while other goods incurred losses in their sales. Consumer demand seems to have adapted and likely to have changed permanently, necessitating corresponding adjustments from supply chains. This new "(ab)normal" (Sheffi, 2020) highlights the long-lasting effects of disruptions and the need for organizations to embrace learning and be agile in responding to changing environments. Though the cost of the pandemic is still evolving, the Institute of International Finance (Campos, 2020)

suggested that global debt will hit around $277 trillion by the end of 2020, whereas the IMF suggested that global GDP will be slashed by $22 trillion (DW, 2021).

Recently, industry has hastily adopted new practices intended to bolster resilience in its operations. Organizations have become more agile in implementing new technologies, adopting smarter or alternate solutions, as well as embracing alternative channels for sourcing and distribution, to mitigate losses in disruptions. For instance, restaurants now offer home delivery and take-out options on their menus, movies are released more often and much earlier via digital in-home (streaming) channels, and working-from-home is becoming increasingly common.

This paper stays abreast of these recent and significant changes by exploring different resilience practices by assessing supply chain literature, i.e. academic and white papers. While numerous definitions of resilience are available, existing definitions do not capture the full scope of resilience. In particular, resilience is a multidimensional feature of organizations that encompasses three elements: (i) degree of impact, (ii) duration to recovery, and (iii) the post-disruption state. The first element relates to the ability of the organization to absorb and resist the effects imposed by the disruption and possibly even to benefit from its effects. The second element has two components: how long it takes the organization to pass the peak of the impact—namely, starting the recovery process—and how long it takes the organization to complete the recovery. The third element is concerned with the organization's ability to learn to adjust its operations and possibly move to a better long-term state post-disruption. Not all organizations will reach such an improved state, as some may suffer long-term adverse effects. Given these observations, we propose an alternative, more comprehensive, definition of resilience and recognize that such a definition is akin to a continuous measure rather than a binary choice.

Beyond the definition, our review of the literature yields additional insights into the manifold supply chain practices that are considered to be important for a resilient supply chain. In total, we classified 32 practices and organized them around the seven core outcomes of disruptions as identified by Caniato and Rice (2003)—supply, internal operations, communications, transportation, distribution, financial resources, human resources—as well as an additional, eighth, pillar encapsulating overarching practices. To assist organizations in their journey towards resilience, we have developed an assessment model for these diverse 32 components of resilient supply chains. This assessment scales the resilience maturity of each of these components from 1 to 5. Thereby organizations are enabled to self-assess and identify their position along the supply chain resilience spectrum and their weaknesses, coupled with guidelines for next steps for enhanced resilience. It should be noted, however, that resilience cannot be guaranteed. Nevertheless, an organization can self-assess its performance along the diverse 32 components of supply chain resilience and embrace these components as levers. Then it can determine which of these levers it should pull to enhance resilience. In the process, it shall decide which ones are more relevant, more important, and offer a better return (reduced risk) on investment, given the trade-offs faced by the organization.

2. Defining Resilience

When a disruption hits an organization, it seeks to protect its core operations and facilitate alternatives to its regular mode of conducting business. Organisations may resort to strategic stockpiling of goods, sourcing alternative suppliers, negotiating with staff for more flexible work arrangements, and expediting the flow of certain goods.

Companies across the world continuously adapt their operations in terms of insurance, inventory reserves, and logistics to manage disruption risks. Over time, industry has been investing in technologies and operations to improve its performances in the face of various disruptions that they confront over time. Businesses harness risk management practices by implementing reactive steps that they deem necessary to avoid frequent disruptions in their performance. Resilience—being an offspring of risk management—focuses on the idea of developing capabilities that a company can invest in by identifying and recording preventive measures against risks as proactive steps, rather than relying on risk management only once the disruptive force is at its doorstep.

Table 1 lists several examples of resilient capabilities harnessed by companies in the past. Through these actions, they were able to quickly switch to alternative options or contain their losses as a result of their pre-planned operational design. Next to each example, we identify the business domain associated with each of the actions. We return to these domains later in this manuscript in our classification of practices (§5).

Table 1. Examples of resilient supply chain capabilities that industry developed to mitigate disruptions in the past

Examples	Domain
In 2005, Hurricane Katrina shut down 95% of crude production and 88% of natural gas output in the Gulf of Mexico. The U.S. Strategic Petroleum reserve released 11 million barrels to the market to mitigate the supply disruption in the USA.	Inventory
In 2020, during the COVID-19 lockdowns, Amazon operated its logistics on a full scale to supply essential goods to consumers directly from supplier warehouses, and also leveraged its logistics as 3PL to various other companies.	Logistics
Leveraging its multiple-supplier sourcing strategy, Nokia responded quickly to the impact of Philips' semiconductor disruptions in 2000.	Sourcing
Dell mitigated the impact of disruption caused by memory supply in the 1999 Taiwanese earthquake by shifting customer demand to lower-memory personal computers.	Demand

Academic literature and media are populated with other examples demonstrating tactics employed by organizations of striving to limit impact, and ensure existence, continuation, and success of their businesses when faced with unprecedented challenges. This ability of organizations to absorb and resist the impact and ultimately bounce back to their original or even bounce forward to an improved performance in a relatively short timeframe is generally defined as resilience. The word resilience originates from the Latin word resiliens, which is the present participle of the verb resilire, meaning

rebound. Resilire itself is a compound of "re" meaning back, and salire meaning to jump. While originally it means bouncing back to the original state, its current usage is broader and encompasses general resistance to external impacts and the ability to restore operations despite a changing environment.

Multiple definitions and concepts have been proposed and adopted in the literature. While this paper does not intend to provide a comprehensive review of such definitions, several key features of existing definitions that ultimately lead to a more comprehensive definition shall be highlighted in Table 2.

Table 2. Sample definitions of resilience (sorted alphabetically)

Authors	**Definition**
Ambulkar et al. (2015)	Firm's resilience to supply chain disruptions is defined as the capability of the firm to be alert to, adapt to, and quickly respond to changes brought by a supply chain disruption.
Blackhurst et al. (2011)	A firm's resiliency enhancers are defined as: attributes that increase a firm's ability to quickly and efficiently recover from a disruptive event.
Brandon-Jones et al. (2014)	SCR is defined as the ability of a system to return to its original state, within an acceptable period of time, after being disturbed.
Christopher and Peck (2004).	Resilience is defined as the ability of a system to return to its original state or a more favorable condition, after being disturbed
Hohenstein et al. (2015)	Supply chain resilience is the supply chain's ability to be prepared for unexpected events, responding and recovering quickly to potential disruptions to return to its original situation or grow by moving to a new, more desirable state to increase customer service, market share, and financial performance.
Juttner et al. (2011)	The apparent ability of some supply chains to recover from inevitable risk events more effectively than others; [it] aims at developing the adaptive capability to prepare for unexpected events and to respond to disruptions and recover from them, [and] is based on the underlying assumption that not all risk events can be prevented.
Kamalahmadi et al. (2016)	The adaptive capability of a supply chain to reduce the probability of facing sudden disturbances, resist the spread of disturbances by maintaining control over structures and functions, and recover and respond by immediate and effective reactive plans to transcend the disturbance and restore the supply chain to a robust state of operations
Pereira et al. (2014)	The capability of the supply chain to respond quickly to unexpected events to restore operations to the previous performance level or even to a new and better one.
Ponis and Koronis (2012)	The ability to proactively plan and design the Supply Chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post-event robust state of operations, if possible, more favorable than the one prior to the event, thus gaining competitive advantage.

Ponomarov and Holcomb (2009)	The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function.
Ribeiro and Barbosa-Povoa (2018)	A resilient supply chain should be designed to prepare, respond, and recover from disturbances and maintain a positive steady-state operation at an acceptable cost and time.
Sheffi and Rice (2005)	An organization's ability to quickly recover from disruption as a characteristic of redundancy and flexibility developed in its supply chain.
Tukamuhabwa et al. (2015)	The adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations – ideally, a better state than before the disruption.
Wang et al. (2016)	A resilient system is a system with an objective to survive and maintain function even during the course of disruptions, provided with a capability to predict and assess the damage of possible disruptions, and enhanced by the strong awareness of its ever-changing environment and knowledge of the past events, thereby utilizing resilient strategies for defense against the disruptions.

A quite comprehensive review of supply chain resilience is carried out by Bevilacqua et al. (2017), who provide further assessment on how definitions of supply chain resilience have evolved to become more comprehensive over time. Bevilacqua et al. (2017) state that the definition offered by Ponis and Koronis (2012)—who reviewed 134 journal articles to craft their definition—is the most complete as it accounts for the following key components of resilience: "adaptation, preparation, response, connection, and control capabilities, as well as timely recovery to return to the original state, or preferably, to a better state". While we do not doubt the scope of the definition, we also observe that resilience is a measure (as explained below), rather than a binary or some vague, assessment of the organization and accordingly can be measured along several dimensions.[1]

Reviewing the literature, Bevilacqua et al. (2017) suggest borrowing the concept of the resilience triangle from civil engineering and use it in the context of supply chains. They demonstrate the resilience triangle concept using the example from Yu et al. (2014). This example clearly indicates that resilience is not a binary value, but possibly a multi-dimensional measure that can take different values. In their example, they simply aggregate the assessment to a single vague measure: high vs. low resilience. In essence, the resilience triangle is a triangle that corresponds to space created between the x-axis, the down sloping line corresponding to the drop in performance due to the disruption and the upward line corresponding to the recovery. Later, in Figure 1, we demonstrate several characteristics disruption profiles. Considering the profiles below the x-axis, the resilience triangle is the stylized profile thereof (i.e., created by straight lines rather than the curved one). Bevilacqua et al. (2017)

[1] Another review of some pertinent literature is available at Elleuch et al. (2016).

generalize the disruption profile using the resilience triangle concept to the context of supply chains, while echoing the disruption profile from Sheffi and Rice (2005). Lastly, they provide a taxonomy for their disruption profile with the embedded resilience triangle suggesting the need to define: prevention, mitigation, recovery, long term impact, and time. One such application that makes use of the resilience triangle is that by Singh et al. (2020) which is applied in the context of food supply chains.

In what follows, (i) an alternative definition to resilience is proposed, and (ii) a comprehensive assessment of the organizational abilities and capabilities that together define organizational resilience is developed.

3. Redefining Resilience

Resilience—or the lack thereof—can be demonstrated in many different ways. In Figure 1, we illustrate several characteristics of resilience paths. The top (blue) path is, to some degree, the ideal and desired one, whereby an organization benefits, sometimes immensely, from an impact disrupting its regular operations. Such an impact could be just pure luck (consider mask makers, like O_2 Industries, who just happened to produce the right product when demand soared) or careful design as described in Taleb (2012) following the concept of anti-fragile. This desired path can be perceived as the black swan of the black swans in the sense that an unusual event disrupts all organizations, but out of these organizations, a select few flourish.

The second (green) path with the shallow trough illustrates a more commonly observed path with impact taking some time to gather force. This was widely observed during the Covid-19 pandemic with effects in Asia percolating steadily through supply chains all the way to other continents, but with the organization requiring longer time to recover. The third (red) path with the deep trough indicates an immediate severe impact to normal operations, as is the case with organizations directly impacted by natural disasters. In this instance, we visualize a quick recovery from the disruptions (e.g., floodings may halt operations, but if no substantial machines are harmed, operations can quickly resume).

Special attention needs to be paid to the positive and negative endings of the depicted trajectories. A positive trajectory implies learning from the impact facilitating improved permanent operations. Such a trajectory can succeed, for instance, when the organization changes its operations in a fundamental way. Consider truck theft leading a firm to install GPS locators, thereby facilitating substantially improved tracking of its fleet, being able to redirect movements, and optimize flows in a more informed fashion. A negative trajectory occurs when the impact is so severe that the organization is unable to restore its performance, for instance due to lack of resources (think of a semiconductor facility where a photolithography machine is damaged due to lightning and, since procuring an alternative machine is expensive and a lengthy process, the company may lose demand and market share permanently).

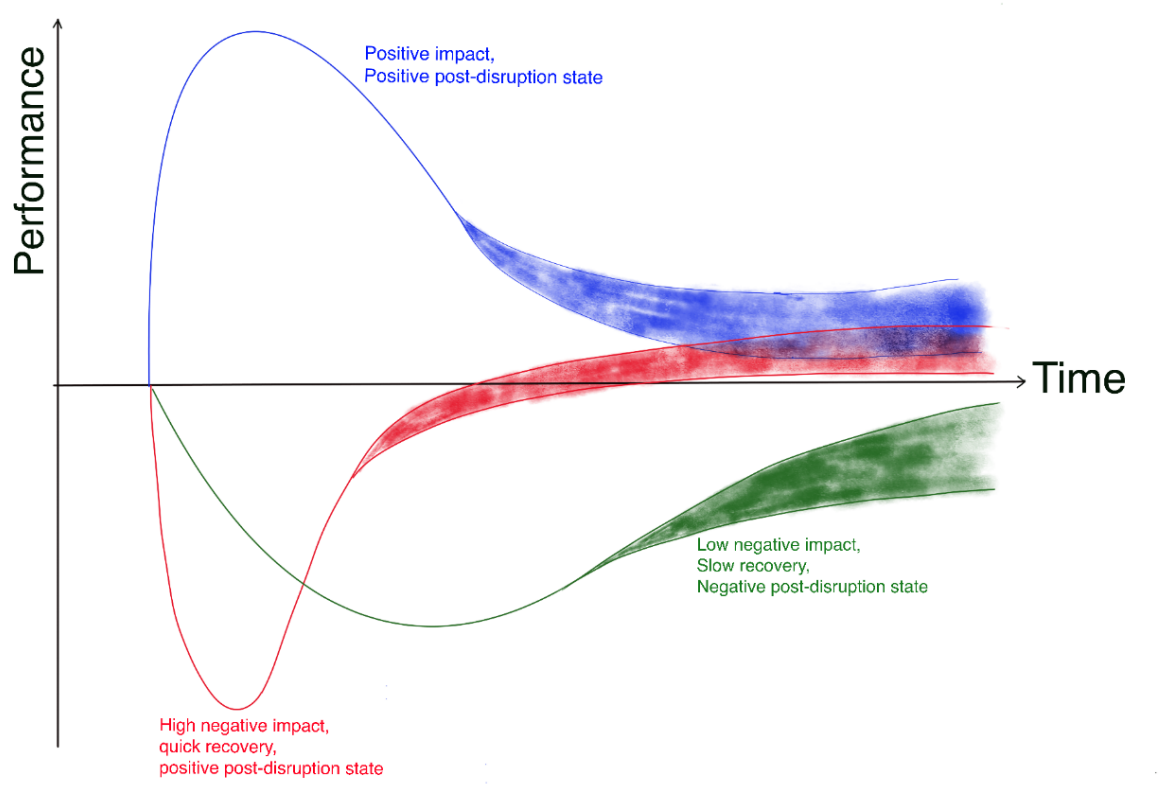

Figure 1.Resilience disruption and recovery profiles

Our review of the supply chain literature suggests that resilience encompasses the following key factors:

- The severity of the impact on the organization. Namely, to what degree can the organization keep performing its activities or not, and can it actually benefit from the impact (though technically, such a feature is referred to as anti-fragile, as per Taleb, 2012)?
- The duration, during which the organization is distressed. How long does it take the organization to reorganize and start the recovery process and actually complete this stage?
- The state of the organization post-disruption. Will the organization end up in a better state, reflecting learning, in the same state, or in a worse state, reflecting permanent loss to its performance?

We have introduced several contributions in the literature that discuss the processes of adaptation, preparation, response, connection, and control capabilities. However, these important processes are not crucial to define resilience but rather important for its implementation, i.e. when one needs to describe *how* to be resilient. Yet, in order to implement resilience, one needs to understand *what* resilience is and what the *degree of resilience* of an organization is. The latter part is instrumental in our definition: resilience is not a binary state, it is a continuum which can be measured. Accordingly, we propose the following.

Resilience: *The degree to which an organization (or a supply chain) is impacted—either negatively or positively—by an internal or external disruption, the duration of the organizational distress and time to recover, and ultimately its post-disruption condition—whether it ends up in a better or worse long-term state.*

To conclude, our definition of resilience measures resilience along three key characteristics. Resilience is not a binary measure—whether an organization is resilient or not—rather, it is a continuous measure with several components. The first measure defines the degree to which the organization can protect its core pillars. The second measure is associated with the speed of reaction to changes in the environments. The third measure, and likely the most challenging one to measure, is associated with a learning process. Namely, the permanent changes in the organization's performance. This requires an agile organization that is open to initiatives and changes, embraces adaptable processes, and proves capable of improving its performance given the insights gained during the disruption.

The proposed measure can serve as a stepping-stone for a better understanding of the concept of resilience and its measurement. In what follows, a general framework for resilience measurement of organizations with an emphasis on its supply chain features is proposed.

4. Design for resilience and the organizational core pillars

Now that we have established a definition of resilience, we proceed to explore commonly-proposed approaches to harness resilience by design (§4.1). This leads us to asses which exact business cores might be affected during disruptions (§4.2) and it will serve as the basis for the classification of practise in the next section.

4.1. Resilience by design

To understand how resilience can be implemented in supply chain design, a brief summary of supply chain resilience design approaches shall be provided. One well-cited approach is that of Sheffi and Rice (2005), who focus on building redundancy and flexibility into an organization's supply chain. Redundancy establishes safety levels to ensure continuity in case of disruptions, for instance, by moving from just-in-time to just-in-case. Redundancy focuses on preserving resources while anticipating potential disruptions and their impact on the organization. The caveat of redundancy is that it can lead to an increase in the overall cost of operations. Flexibility, on the other hand, focuses on building capabilities and adding resources in a way that allows responses to threats as soon as they are detected. Sheffi and Rice (2005) argue that resilience hence offers a competitive advantage for an organization and demonstrate the potential for resilience along five core elements of supply chains: supply and procurement, the conversion process, destitution channels, control systems, and corporate culture.

Inman and Blumenfeld (2014) highlight two key factors in supply chain resilience: prevention and mitigation. The former aims at reducing the probability that risk materializes in the first place, while

the latter seeks to prepare supply chains for absorbing risks once they occur. Prevention and mitigation are complementary, and it is desirable to employ them both.

In a similar fashion, Melnyk et al. (2015), consider two key factors: resistance and recovery. In their discussion, they identify eight categories of resilience-oriented investments: discovery, information, supply chain design (here suggesting a supply chain can be reconfigured in response to changes), buffers, operating flexibility, security, preparedness, and indirect investments (these include other domains often intended to create goodwill (e.g., via loyalty), and other areas that can support recovery).

Sáenz et al. (2018) offer a broader framework for supply chain resilience design. They disentangle features of supply chains while recognizing that companies organize their supply chains based on their respective idiosyncrasies. As with other frameworks, they have two components in their supply chain risk management consideration: reactive and proactive. They further account for internal vs external vulnerabilities coupled with the scope of their supply chains: global vs local, while paying attention to competitive priorities of supply chains. They conclude with a roadmap to guide such decisions.

Research Luxembourg (2020) identified a number of factors, which can also be thought of as leverages, that characterize supply chains and can serve as decision points on how to (re)organize their supply chains. In particular, they identified the following levers: degree of globalization, product complexity, supply slack, length of supply chain, narrowness of supply chain, opacity, and production volatility. Most of these features are illustrated in Figure 2.

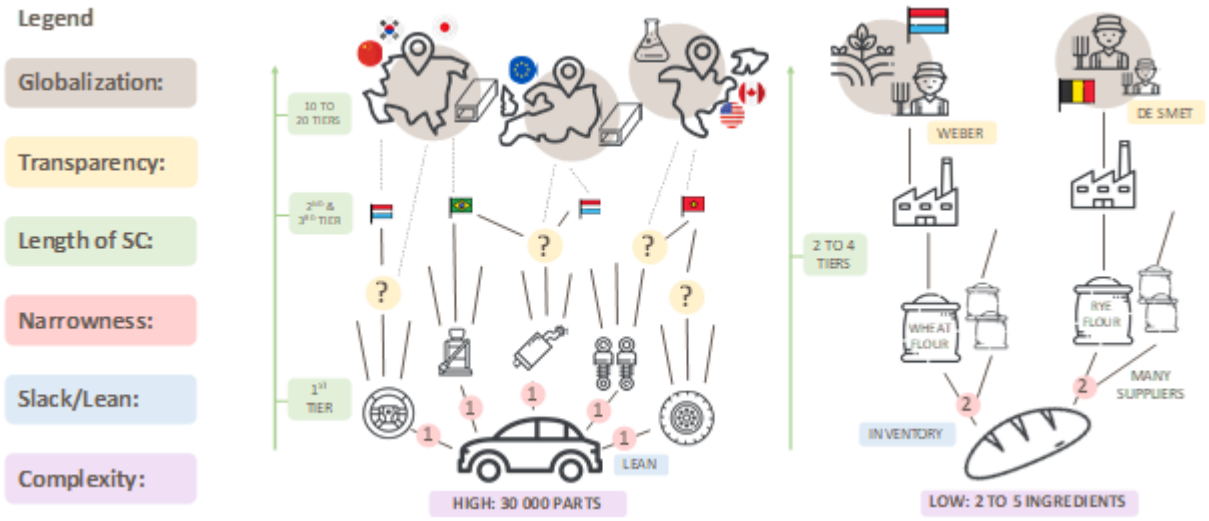

Figure 2. An illustration of key supply chain characteristics (Source Research Luxembourg (2020))

4.2. Mapping disruptions to organizational core pillars

The assessment of how resilient an organisation is requires evaluating the core domains that may be affected by disruptive events. Disruption in supply chains is a common phenomenon, often due to unprecedented external or internal factors such as supplier fraud, machinery failure, or faulty products. Notable recent disruptions, which have disrupted flows of goods between countries on a large scale, include the COVID-19 pandemic, Brexit, and the America-China trade war. Industry continuously strives to include resilience in its operations, as this leads to a reduction of the severity of disruption, which in turn will minimize loss and maximize recovery speed.

Supply chain disruptions and their recorded magnitude of impacts on major industry branches or geography, and the corresponding core activities that were primarily impacted by these disruptions, are mapped in Table 3 below. Here, this work draws from the seven cores of organizations impacted by supply chain disruptions as identified by Caniato and Rice (2003): supply, internal operations or production, transportation, communication, distribution, financial resources, and human resources.

Table 3. Examples of major disruptions on supply chains

Disruptive Events	**Year**	**Impacts Recorded**	**Core Activities Disrupted**
Financial Crisis	2007-2008	The financial and economic crisis cost Americans $12.8t (Puzzanghera, 2012). Chrysler and General Motors filed for bankruptcy in 2009 as new car sales dropped by 30% (Sheffi, 2015).	Financial Resources
Eruption of Eyjafjallajökull	2010	100,000 flight cancellations, at a cost estimated at $2-$3.3b by airlines, airports, and tour operators (Banker, 2010). Nissan and BMW had to halt their automotive production because of disruption in air supply.	Transportation
Tōhoku earthquake and tsunami	2011	The direct economic loss from the earthquake, tsunami, and nuclear disaster is estimated at $360b. By March 2012, 644 companies (157 services, 154 manufacturers, 113 wholesalers), which employed around 11,412 people, had filed for bankruptcy (Sheffi, 2015).	Communication, Distribution, Production
Thailand Floods	2011	Western Digital hard disk drive manufacturing company was severely affected as 60% of the facilities shut down. By Q4, it saw a 51% decline (from 57.8m to 28.5m units) of HDD shipment, while Seagate saw an 8% decline (from 50.8m to 46.6m units) of HDD shipment (Haraguchi and Lall, 2011).	Supply, Production/ Internal Operations
Horsemeat Fiasco Europe	2013	The horsemeat scandal wiped out £300m of Tesco's market value.	Supply

COVID-19	2020	The Institute of International Finance (Campos, 2020) suggested that global debt will hit around $277t by the end of 2020. Later, the IMF estimated the global GDP to be slashed by $22t (DW, 2021).	Human Resources, Distribution, Operations.

The identified core activities correspond to traditional business functions of organizations. Specifically: supply maps to procurement, internal operation maps to production, distribution maps to sales and marketing, communication maps to IT, transportation to logistics, financial resources to finance, and naturally human resources to HR.

The steps or measures taken by organisations to overcome major external and internal supply chain disruptions can lead to newly-designed processes and are elaborated on in the next section.

5. Classification of practices in supply chain resilience

Melnyk et al. (2015) describe resilience as a derived system property, obtained as a result of investments made in a firm over time to improve its performance. Sheffi and Rice (2005) suggest resilience to be a strategic initiative within the organization. To guide organizations in their path towards resilience, we further explore initiatives and classify investments in resilience, elements or processes that correspond to the seven cores affected by disruptions (Rice and Caniato, 2003).

Table 4 provides an overview of the diverse practices and supply chain processes found in the expansive literature. Clearly, no one approach or a defined set of practices fits every organization. Implementing resilience may depend on the varying characteristics of the organisation such as its position within the supply chain (i.e., close to consumers or closer to raw materials), the type of products it offers, or its supply chain configuration (recall Figure 2). We shall note that the list of practices is comprehensive, and the relevance of these practices is company-specific, meaning that a company might find only a subset of these practices to be relevant given its size, industry, or location within the supply chain and so forth. Overall, mapping resilience practices can support organizations in their decisions on the most appropriate set of actions to take.

Importantly, this work has identified a set of actions that does not fall into either of the seven cores of Rice and Caniato (2003), but instead are overarching practices. These practices, which fall within the responsibility of executive leadership of the organization, are: risk mapping, digitization, automation, and scenario planning.

Table 4. Classification of practices in supply chain resilience

Overarching practices	Risk Mapping	Scenario Planning	Digitization	Automation
Supply	Supplier performance	Supplier visibility	Multi-sourcing	Nearshoring
	Supplier Relationship	Supplier Inventory		
Internal Operations	Location flexibility	Capacity flexibility	Product Complexity	Master planning and risk assessment
Communication	Interactions with stakeholders	Organizational visibility	Backup of data and parallel (mirrored) IT system	Data security
Transportation	Transportation flexibility	Logistic Service Providers (LSPs)	Warehousing flexibility	Logistics visibility
Distribution	Marketing	Packaging	Inventory management	Customer services
Financial Resources	Financial reporting	Insurance policies	Liquidity	
Human Resources	Tracking workforce availability	Business continuity	Skill mapping and workload sharing	

5.1. Overarching practices

The four overarching practices that were identified in the precious section fundamentally influence the degree of resilience of an organization: whether it engages in the practice of identifying and mapping risks, whether it facilitates scenario-planning activities, and whether it embraces digitization and automation throughout the organization. This paper will elaborate on these in the following sub-sections.

5.1.1. Risk mapping

Risk management is one of the first steps to identify the impact of risk on the organization's operations. Sheffi (2015) illustrates how risks can be classified into four quadrants based on two key categories: the likelihood of the risk (following a spectrum of outcomes ranging from low to high) and the severity of impact (ranging from low to high). For instance, a firm may have classified Brexit as an event of high likelihood of occurrence with potentially severe impacts on the organization (e.g., due to disruptions of flows of goods between the UK and mainland Europe), whereas another firm may have classified Brexit as having limited impact on the firm (e.g., a European firm with no components sourced from the UK). Another example is exposure to sea/airport strikes. For companies that rely on flows through such important nodes in the network, the risk is of high impact, whereas companies that rely on local suppliers may classify it with limited risk, or no risk at all. Organizations need to regularly map potential risks, and how they evolve over time—and with that the varying likelihood of occurrence and degree of impact—to ultimately develop an action plan. Sheffi suggests to design routine business processes to smoothen out the effect of low-impact events. Low-likelihood, high-impact events include, among others, the black swan-type events, and reflect the category that risk managers may fail to

account for. The high-likelihood, high-impact events require mitigation plans that can be quickly facilitated.

Apart from these two dimensions of risk—likelihood and impact—Sheffi (2015) considers another important dimension: the degree of catastrophe detectability. The detectability of catastrophes can have both negative and positive values. Risks of disruption may be detected before, or after, their onset. The growing population in India and China (both of which require intensification of infrastructure to avoid future shortages and disruptions) and the aging population worldwide are examples of events with long positive detectability. The looming climate crisis is an example of an event with shortened positive detectability, whereas weather systems such as hurricanes, develop over a matter of days and allow planners a rather short window of preparation. Instances for negative detectability lead-time include manufacturing defects as experienced by Mattel Toys. In this case, the paint on several of Mattel's toys contained a high amount of lead, which was only discovered after these toys were already shipped to customers throughout the world. Another example is Honda's recall of 65,000 cars in India due to faulty fuel pumps.

The concept of resilience in supply chains is derived from recent studies of risk management. Another aspect of risk mapping was raised by Tukamuhabwa et al. (2015) and relates to the source of the risk. They observed that risk management usually refers to identification and classification of the risks along with their consequences. Supply chain resilience, on the other hand, provides tools to identify, quantify, and record risks for their varied impacts. Along with supply chain vulnerability and supply chain risk management, resilience complements supply chain management. To that end, Tukamuhabwa et al. (2015) designed a taxonomy of vulnerabilities in the supply chain as a result of external and internal factors. Specifically, they offer five categories of external threats: political, economic, natural, competition, and technology, all of which can influence or compound with internal threats, and which are classified into downstream, upstream, or within firms.

External threats are not controllable by companies, and resulting supply chain disruptions induce instability in the internal supply chain. A disruption originated in the network sends shockwaves throughout the whole supply chain process. Internal threats such as supplier fraud and defective products, tend to be frequent and are generally short-lived.

Supply chain vulnerability also studies the possibility of threats that any operation of the organization may be exposed to due to the complexity of the product and its global or local dependability from source to demand. The design and complexity of a supply chain network scale with the complexity of the product that is delivered at the end of that supply chain (Inman and Blumenfeld, 2014). For instance, the number of parts in a product such as an automobile and smartphones with newly added sensors demand an increase in supply chain branches, which impacts the complexity of the supply chain.

5.1.2. Scenario planning

Scenario planning involves building models around several anticipated risks to proactively develop plans on how to overcome such risks and possible disruptions. Coates (2016) emphasizes scenario planning in supply chains as a factor of a complex and unfamiliar business environment, which requires starting by identifying the scenario's qualitative and quantitative values. Scenario planning (re)models plans for permanent changes in operations to ensure that negative outcomes of identified disruptions are minimized. Scenario planning handles long-term trends such as 3-D printing, remote work location models, etc. Dolguib et al.'s (2018) scenario planning and scheduling model demonstrates that pre-decision of scenario planning and recovery schedules lead to improved performances. Companies that engage in scenario planning are capable of detecting trends and deviation early and thus devise master plans accordingly. One such company is Shell (Bentham, 2014), which regularly engages in this practice, which, in this context, led to Shell's initiative to decarbonize its operations.[2]

5.1.3. Digitization

Digitization in supply chains entails recording, restoration, and reusing of all operations and transactions on digital platforms. Kilkner (2020) in his post-COVID-19 survey concludes that digitization in supply chains directly links to resilience. He demonstrates that companies with advanced digitization adaptabilities have shown faster recovery rates than those who lag behind. van Donk (2008) gives a brief overview of how Information and Communication Technology (ICT) has resulted in new business models across all industry branches which he denotes as 'new economy'. He further emphasizes that business have migrated to Enterprise Resource Planning (ERP) system or Electronic Data Interchange (EDI), and started embracing new technologies like RFID. Digitization in operations includes technologies such as Software as a Service (SaaS), blockchain, cloud computing, big data analytics and provides opportunities for the enterprise to improve visibility, connectivity, and live data sharing across the supply chain. Efficiently integrated operations on digital platforms give staff the opportunity to easily locate bottlenecks and remove hurdles, identify disruption, set up reactive measures, and share details with multiple agents across the supply chain. The use of machine learning is providing companies with forecasts on demand and supply and thus preparing them beforehand to meet anticipated changes to reduce chances of being caught unprepared.

5.1.4. Automation

Automation often relies on the availability of data to facilitate automated processes and hence heavily relies on digitization practices. According to Viswanadham (2002), automation technologies have proved to accelerate and streamline processes across supply chains especially in warehouse management, distribution, and logistics. Automation helps to anticipate risks and develop measures to

[2] See also https://www.shell.com/energy-and-innovation/the-energy-future/scenarios.html.

reduce the chance of disruptions. Dehnhardt et al. (2016) further list automation and digital technologies as technologies that increase operational performance while reducing risks of operational slowdown during disruptions. Their list further mentions blockchain for secure data distribution and operation visibility, augmented reality to improve distant operational activities, robotics, and autonomous logistics to reduce human dependency, digital platforms, and SAAS core solutions to reduce data errors by automating validations, 3D printing, and big data analytics.

5.2. Supply

Supply refers to the upstream side of networks. Specifically, in a supply chain it relates to the agents and processes involving materials and services from the source (such as raw materials) to the current focal entity. Any threat or disruption occurring to geography and industry from which goods or services are sourced may result in a wide range of disruptive outcomes across the network. Ranking suppliers according to the risks they may face and developing processes to mitigate such risks is a critical practice to adopt. This requires frequent monitoring of the supply network and engaging in supply design decisions. More details are provided below.

5.2.1. Supplier performance

According to Handfield et al. (1998), supplier performance is the process of mapping suppliers, items and services for their diverse KPIs, such as quality, quantity, delivery speed, performance, and responsiveness. van Weele (1984) suggests that the need for monitoring (and ultimately improving) supplier performance rose not only for cost management reasons, but also for reasons of quality. Supplier performance is generally facilitated via scorecards, which link suppliers with their items and services for their quality, quantity, and delivery speed. Such mapping assists enterprises to foresee supply chain-related risks. Specifically, it can help to foresee potential supply disruptions and, hence, require and enable timely implementation of methodologies to ensure supply continuity.

5.2.2. Supplier visibility

Fan et al. (2013) note that one of the main reasons due to which supply chains become complex and difficult to manage is the rise of many multi-tier suppliers in an ever-growing supply chain network. Visibility is the enterprise's access to its supplier's location, finances, and supply risks (mainly order fulfillment) and is often achieved through electronic connectivity. However, such connectivity and collaboration are generally limited to first-tier suppliers, as critical components from deep-tier suppliers have limited visibility, if at all. Fan et al. (2013) identify a number of approaches for organisations to improve visibility of lower-tier suppliers: lower-tier supplier certification, dual function, direct contract with lower-tier suppliers, oversight of multiple functions, lower-tier supplier empowerment, deep down multi-tier probing and inter-supplier collaboration. For a resilient supply chain, an enterprise should have insight into its suppliers' suppliers (i.e., deeptier suppliers). Supply chain transparency across the supply chain network allows tracing vulnerability to disruptions that upstream suppliers are potentially

exposed to. Once potential risks are identified, companies can implement subsequent resilient frameworks possibly in collaboration with their suppliers.

5.2.3. Supplier relationships

Forkann et al. (2016) observe that supplier relationships are prone to risks from managerial challenges, technology, and suppliers potentially turning into competitors. To address such challenges, companies need to focus on the structural composition of the supply base by: (i) keeping firms aligned to changing business environments, (ii) identifying financial (fading relationships) and non-financial (limited innovations) supply base threats, (iii) actively managing suppliers through contracts and (iv) developing an organizational process to initiate, develop, and end supplier relationships (Capaldo, 2007; Eisenhardt and Martin, 2000; Forkmann et al. 2016; Mitrega and Zolkiewski 2012; Teece et al., 1997). Another aspect of a strong supplier relationship is information-sharing, which is critical for early detection of disruptions. Ideally, supplier-buyer relationships facilitate information-sharing between the two agents and other aspects of mutual support. Additional modes of mutual support provide safety nets for business continuity and faster recovery. Innovation, as reviewed by Kumar et al. (2020), is best observed in the supply network where suppliers and buyers work collaboratively. They conclude that the two supply-network actors—i.e. the buyer and the supplier—shall produce enough innovative efforts to increase their resilience to global shock.

5.2.4. Multisourcing

Banker (2020) notes that access to alternative, pre-qualified suppliers prevents discontinuity in case of disruptions. This also mitigates risks of fake and/or defective product supply during crises. The availability of alternative suppliers also depends upon their location. Ideally, primary and alternative suppliers shall be sufficiently differentiated to avoid exposure to shared risk.

5.2.5. Nearshoring

According to Galea-Pace (2014), nearshoring refers to the activity of identifying and engaging suppliers closer to facility locations. Nearshoring helps companies to reduce geographic dependence on their global networks and shorten the cycle-time of finished products. It enhances control over inventory and moves the product closer to the customer.

5.2.6. Supplier inventory

Inventory management is a crucial factor in creating resilient supply chains. Sheffi (2015) acknowledges that striking the right balance between just-in-time and just-in-case inventories is crucial during disruptions. Firms need to find the right choice for the products given their indispensability and lifecycle. A company is resilient to supply disruption when its suppliers' time to survive the crisis is higher than the time for recovery after the crisis ends. Just-in-case inventory for critical materials increases survival, while just-in-time inventory helps reduce waste and increase efficiency for product

availability. To ensure resilient supply, the buying company could develop collaborative partnerships with suppliers to gain access to their inventory management. Suppliers and buyers can collaboratively identify risks that suppliers may be vulnerable to and maintain inventory levels to mitigate the loss of disruptions. A discussion on inventory stress tests while balancing Time to Recovery (TTR) and Time to Survive (TTS) is offered by Simchi-Levi (2015) and Simchi-Levi and Simchi-Levi (2020).

5.3. Internal operations or production

Internal operations refer to the production or services that are bound to a firm's core processes and define its identity. Companies' internal operations are most vulnerable to threats originating in supply or in internal failures in operations. If firms are to minimize and to limit the impact imposed by threats, they need to survey their facilities and locations, to assess any potential threats, to allow for independent monitoring of such threats, and to develop resilience-action plans. This work has identified some of the practices in resilient supply chain design associated with internal operations.

5.3.1. Location flexibility

Carr (2018) defines location flexibility as the ability of firms to gravitate units and production among different locations across the supply chain network. Location flexibility allows firms to shift activities from a disrupted location to an alternative one with minimal effort.

5.3.2. Capacity flexibility

According to Altendorfer (2017), capacity flexibility allows organizations to adjust their output level to the changing market needs, in general, and in the event of a disruption, in particular. This requires capacity planning to start with identification of bottlenecks and often involves simulations of operations with assumed risks and scenarios among the suppliers, logistics, and production. A simulation model using augmented reality identifying what-if scenarios can help in designing resilient capacity planning.

5.3.3. Product complexity

Product complexity accounts for (i) the number of components required in manufacturing a finished product, and (ii) the uniqueness of components in the final product. A product's vulnerability to disruptions increases with the number of parts of which it is composed and with the uniqueness of each component. Jacobs (2007) notes that standardization of components, or reducing the number of unique components, and making them compatible with alternative components during the product design phase, can improve the flexibility of companies to source substitutable components from alternative suppliers. With the diminished risk, companies can also reduce safety-stock levels.

Inman and Blumenfeld (2014) illustrate the relationship between probability disruptions in plant operations and increased product complexity. When this complexity goes unnoticed, disruptions in plant operations become frequent phenomena, thus leading to a very high probability of disruptions, also referred to as unmanaged risk. To contain this instability in plant performance, companies might come

up with multiple resilience actions such as increasing inventory of critical components, changing freight options, and sourcing from multiple suppliers. Actions, which add value to consistent plant operations by eliminating high disruptions, are also referred to as managed risks.

5.3.4. Master planning and risk assessment

Forecasting, demand sensing, assessment of risks, product design, and other planning features contribute to preparedness during crises. Simulations of master plan disruptions and adding further resilience steps to identify best possible solution(s) support a proactive resilient supply chain design. Dolguib et al. (2018) offer a model to integrated supply chain resilience design analysis with master scheduling. Their model measures schedule recovery in periods of disruption, performance impact assessment, duration of disruption, and impact of disruption on economic performance; the latter being an indicator for decision-makers for the trade-off of performance vs. resilience.

5.4. Communication

Communication is the ability to access information related to supply chain processes, gather data, analyze, and forward processed data for better and optimized supply chain performance. With the advent of big data technologies, storage, and access to information across supply chains, the usage of this data in various data modeling and forecasting tools has been adopted literally by all companies. While this allows improved performance and enhanced market competitiveness, this new access to information is now facing threats from a growing number of cyber attacks. Further, availability of the right information at the right time continues to remain challenging in the age of ever-growing data volume. This paper has identified a number of practices, which address companies' concerns over usage and protection of their data across supply chain networks.

5.4.1. Interaction with stakeholders

Stakeholders are individuals or organizations with interests in companies' operations. They include, among others, suppliers, service providers, financial institutions, and consumers. Effective social networking and communications are crucial for companies to gain and assure trust from their stakeholders, to engage them, and to advertise for cooperation among supply chain players by sharing and exchanging information in a timely manner (Darkow et al., 2013; Houghton et al., 2009). Asamoah et al. (2020) note that informed stakeholders might overcome disruptions more easily, as they are better prepared through shared responsibilities and risks, as well as social support. Further, input from stakeholders can provide important perspectives for resilience.

5.4.2. Organizational visibility

Stakeholders along supply chains are well aware of the importance of a seamless flow of goods and information. Information distortion plays a role in supply chains, so stakeholders also need to investigate and develop suitable information systems to address such informational distortions—a

domain that deserves further research (Lee et al., 1997; van Donk 2008). Aided by information technologies, organizations can improve visibility of their operations and speed up communication along supply chains. Digital technologies can facilitate early detection of internal disruptions, enhance visibility, and support information-sharing, all of which can improve reaction time to disruptions.

5.4.3. Backup of data, parallel (mirrored) IT system

Data backup ensures that a copy of all information is securely stored. A parallel IT system involves a secondary server that replicates the primary server used for the company's operations. Caniato and Rice (2003) observe that data backup ensures that firms can recover in case of data disruption (e.g. due to theft, hacking, or server breakdown). A parallel IT system enables companies to continue operations in the event of a primary system disruption.

5.4.4. Data security

Organizations' IT infrastructure is often under threat from external and internal sources such as hackers who seek to compromise the system to, for instance, gain insights into the firms' operations and technology. Chidambaram et al. (2018) conclude that data security shall minimize the risk of such disruptions. Organisations usually prefer users (i.e., employees) to strictly use corporate devices and networks to avoid any chances of leakage and security attacks. Firewalls act as a barrier between a trusted internal system or networks and outside connections. While data brings in profitability and efficiency in business, disastrous breaches can lead to financial and brand value loss. Communication networks in supply chains can be made more resilient by, e.g., frequent review of safety measures; ensuring role-based access control; and keeping up-to-date endpoint protection software, antivirus and firewalls, data encryption, and tokenization.

5.5. Transportation

Transportation in supply chains includes the means and modes to move goods and services across supply chain networks. Colon et al. (2019) note that transportation is a module in the supply chain that connects multiple components of an economy. This module connects raw materials to manufacturers and communities, while at the same time making sure that finished products reach consumers. Transportation in the supply chain is an important factor and it is most vulnerable to negative external events such as natural disasters, strikes, technological breakdowns, and political/governmental blockades. A resilient transportation system focuses on identifying factors that address its design and needs, as well as finding methodologies and technologies that contribute to its improved performance during disruptions.

5.5.1. Transportation flexibility

Markolf et al. (2019) define transportation flexibility as the adaptability of logistics in terms of routes, volumes, mode, and technology, with recurring changes in demand characteristics. Flexibility in

transportation significantly reduces any efforts (and costs) needed for firms to adjust (e.g., to alternate modes or routes, change in volumes) in the event of disruptions.

5.5.2. Logistics Service Providers (LSPs)

Gerosa and Taisch (2009) identify LSPs to be positioned, by design, both in upstream and downstream segments of the supply chain. LSPs possess expert knowledge on transport and externally-related risks in the partner's geographic environment, which makes cooperation with them critical. Close co-operation with LSPs for monitoring risks and setting up resilient actions helps organisations create an effective transportation design.

5.5.3. Warehousing flexibility

An assessment of the concept of warehouse flexibility requires deep understanding of local and regional complexities, facility location, distribution, materials live-tracking, automation, and robotics (Custodio and Machado, 2019; Demirel et al, 2010). Together, these elements contribute to resilient warehouse designs in supply chains. Gravitating facility centers closer to the market can decrease chances of supply disruption. Robotics and live inventory tracking improve inventory visibility and can help in monitoring demand in certain regions. Flexible warehouses can use open warehouse space concepts to adjust and match consumers' needs. Smart barcode scanning capabilities enable companies to manage warehouse capacities with rapidly changing demand during disruptions. Another option is resource pooling with similar businesses in shared warehouses. While challenging from a competitive perspective, the co-operative element (leading to a co-opetitive outcome) lets the firms involved decrease their warehouse cost, while facilitating rotation and redistribution of excess stocks before expiration.

5.5.4. Logistics visibility

Markolf et al. (2019) highlight the importance that logistics visibility of capacity and transport is available for movement of inventory, thereby giving an opportunity for companies to speed up recovery measures in case of disruptions in supply or delivery of products and services. By monitoring the flows, firms can better assess their risks and plan accordingly. Visibility also allows more flexibility and redundancy over the use of routes, and logistic capabilities over assumed or foreseen risks.

5.6. Distribution

Distribution is the process of supplying (finished) products to the company's customers in the supply chain. Rexhausen et al. (2012) notice that, traditionally, distribution is considered as the link between companies' internal supply chain and their customers. The role of distribution for improving supply chain performance has increasingly gained importance among members of distribution management teams. Distribution is sensitive to consumer behavior. Changing consumer behaviors affect how the product is consumed, and hence how the product should be marketed, packaged, and so forth. As such, companies shall be very attentive to the constantly changing consumption patterns and integrate

relevant forecasts into their distribution planning. In what follows, this work focuses on several practices that influence distribution resilience in supply chain management.

5.6.1. Marketing

Marketing is an important link to consumers. Gölgeci and Kuivalainen (2020) note that close alignment of supply chain resilience with marketing facilitates benefits of risk absortive capacity within the organization. Thus, deploying marketing effectively during turbulent times can improve organizational capacity. Close collaboration between marketing and supply chains enhances forecast accuracy and minimizes inventory-demand mismatches.

5.6.2. Packaging

Packaging refers to the preparation of products for safe, cost-effective, and efficient transportation. McDonald (2016) identifies packaging as tangible for physical goods and as non-tangible for services. A number of actions can contribute to a resilient packaging system: collecting data for packaging materials, measuring performance of packaging systems, identifying improvements and underperforming packages, and identifying and simulating risks with innovative methodologies and technologies, such as tracking and computerized models.

5.6.3. Inventory management

Inventory is the stock of materials or goods such as raw materials, semi-finished goods, goods in transit, or work-in-process that a business holds for the ultimate goal of use or sale. According to Sheffi (2015), it is crucial to find an equilibrium between just-in-time and just-in-case inventory to manage disruptions. This includes tracking inventory movement during the distribution process, and assess backup plans in case of any risk or disruptions identified on the spot.

5.6.4. Customer service

According to Huo (2012) customer service encompasses various types of consumer contacts such as delivery of goods, engaging and assisting consumers with purchased products and services, and generally being responsive to customers' needs. Customer service can obtain real-time metrics on customer experience and changing needs to proactively implement changes in firms' operations in a timely fashion. Asamoah et al. (2020) emphasize customer-oriented performance on internal and external social networking as interaction among all supply chain players. Different levels of internal and external interactions aim to engage customers, government authorities, political leaders, and institutions to obtain necessary resources, such as insights on levels of satisfaction, in order to enhance business performance.

5.7. Financial Resources

Financial resources refer to all financial funds of the organization. They can be structured into business funds, corporate capital, and other factors that directly or indirectly influence the balance sheet of an organization.

5.7.1. Insurance policies

Njegomir and Richter (2017) highlight that for unforeseen risks, insurance helps businesses to reduce financial loss in case of the occurrence of a negative impact. Insurance helps to ensure financial stability for an organization to overcome a crisis. Carrying out a risk-management audit to identify potential liabilities and accident costs is recommended. Diverse types of business insurance policies can be essential to support supply chain operations.

5.7.2. Liquidity

Liquidity relates to the company's assets which can be readily converted to cash. Assets like inventory, bonds, and stock shares are affected when a crisis hits, which could negatively impact their value; in such a case, companies might face difficulties obtaining cash to keep operations going. Popa (2013) concludes that building cash reserves, identifying varying liquid assets, investing in operations, and collaborating with institutions can help with enabling long-term cash flow, which in turn will increase organisations' resilience.

5.7.3. Financial reports

Financial reporting uses financial statements to disclose financial data that indicate the financial health of a company during a specific period. Lan and Zhong (2016) suggest that the quality of corporate financial reporting is not only related to the internal accounting process(es) of a company but also to a variety of external factors. Financial reports help firms to determine availability of funds and other financial assets, which they can deem necessary to re-evaluate and modify during a crisis. Several types of financial reports are commonly found:

a) Short-term and long-term cash forecasting: helps organizations identify short- and long-term cash shortfalls and thus come up with remedy plans.
b) Pending debt or bond issuances for long-term cash position.
c) Debt covenants: these are agreements between a company and a creditor usually stating limits or thresholds for certain financial ratios that the company may not breach. Their projection is a vital component of a financial model.
d) Receivables/credit losses.
e) Hedging: A hedge is an investment, contract, or agreement for future transactions that are made to reduce the risk of adverse price movements in an asset.

f) Assessment of business disruptions on the workforce from a financial perspective: may help organisations to identify financial transactions related to idle workforce.

g) Assessment of business disruptions on inventory: this report may contain information like lacking inputs, excess stock, etc.

h) Scenario modeling for financial forecasting.

i) Financial asset valuation.

j) Quarterly financial statement preparation and filing timeline.

k) Restructuring: Restructuring costs are reported when a business incurs one-time or infrequent expenses in the process of operational reorganization to improve its long-term profitability and efficiency.

l) Revenue recognition: this report identifies the specific conditions under which revenue is accessed and determines how to account for it. Typically, revenue is recognized when a critical event has occurred, and the amount is easily measurable

m) Asset impairment: Tangible and intangible impacts of book value on assets.

5.8. Human Resources (HR)

Human resource management is the efficient management of a workforce in any firm. Similar to supply chain management systems, human resource management maintains relations across interrelated departments with varying job responsibilities working to achieve common goals. Lengnic-Hall et al. (2011) summarize that effective human resource management is responsible to communicate the core values of the organization. HR is tasked with developing and managing labor capacity for resilience by training and motivating individual resilience, fostering deep social capital (Lengnic-Hall et al., 2011), resourcefulness, bricolage and ingenuity (Coutu, 2002; Eisenhardt and Tabrizi, 1995; Lengnic-Hall et al., 2003), as well as nurturing diffused power and accountability (Morgan, 1997).

5.8.1. Tracking workforce availability

Identifying tasks which match employees' skills and roles in an organization is linked to communicating and tracking employees' availability. Lengnic-Hall et al. (2011) relate this type of human resource management to the cognitive and contextual dimension of organizational resilience. Workforce tracking can be an important factor in the development of a resilient supply chain for a crisis when staff is unable to make it to the site to carry out activities. Tracking workforce entails grouping employees according to their dispensability, skills, roles, travel needs, or on-site presence.

5.8.2. Workforce business continuity

Business continuity in the workforce is the process of creating systems for prevention and recovery in case of a potential loss of workforce due to disruptions. Business continuity planning is essential to keeping people productive during planned or unplanned disruptions and to protect businesses from consequences such as financial losses, damaged reputation, weakened customer and partner

relationships, as well as lost productivity. Following Ruiz (2005), ideas for business continuity plans rely on basic risk management tactics and risk-mitigation plans by, e.g., relocating manufacturing facilities (Carr, 2018) and critical workforce to different locations. A complete business continuity plan must encompass both data and workforce recovery, with technologies and best practices to ensure seamless operations when disruptive events occur.

5.8.3. Skill mapping and workload sharing

Preparedness for loss of workforce or increased needs due to disruption is a guiding idea behind skill mapping. Absenteeism can be a major hurdle during disruptions. Garber (2008) notes that some of the resilient methodologies that can be developed within organizations entail identifying shortfalls and developing alternatives. Alternatives include cross-training to fill gaps, bringing in additional temporary workforce on critical tasks, and reducing dependency by introducing automation, transferring redundant tasks to machines, which ultimately leave intelligent tasks to humans.

6. A self-assessment tool

The assessment tool incorporates factors identified earlier from the discussed literature and links them to the seven outcomes of disruptions by Caniato and Rice (2003) and to the overarching executive roles we distilled. Accordingly, the different domains in the assessment tool can be carried out by the corresponding entity within the organization (i.e., by stakeholders form the following departments: procurement, production, sales and marketing, IT, logistics, finance, HR, as well as from the executive level).

This work developed a five-step scale towards enhancing resilience levels as a guiding tool for organizations to further their resilience design. The rating measures the proactive characteristics of a company's leadership in its supply chain resilient design; elements of supply chains and their resilient capabilities in an organization and sector; and the level of resilience the organization can achieve.

Accordingly, the levels of the scale identify progression along the spectrum of resilience practices in the following order:

1. Open – the organization does not act upon disruptions until such events occur.
2. Aware – the organization makes first steps towards resilience.
3. Reactive – the organization is able to respond, to a limited degree, to disruptive events.
4. Prepared – plans are in place to enhance continuity.
5. Resilient – integration is in place to enable cutting-edge practices in this context.

This self-assessment allows organizations to evaluate or judge where they stand with respect to their supply chain resilience and accordingly identify next steps. Not every aspect of supply chain resilience outlined in the assessment fits every organization, and as such, organizations can skip aspects that are of limited, or no relevance, in their context.

The full assessment is provided in the Appendix. For each assessment entry a full description is developed along the 5 levels of the resilience scale. A supporting self-assessment tool (for instance using excel which is available upon request from the authors) then allows completion of the assessment and visualization of the organization's performance. For instance, Figure 3 illustrates a radar chart depicting outcomes of the assessment along the six assessment entries in the supply pillar (see §5.2) for a hypothetical firm. A decision-maker from this firm can then determine whether it is in the best interest of the organization to invest in multi-sourcing, supplier performance, and/or supplier relationships—three aspects on which the firm ranked somewhat low.

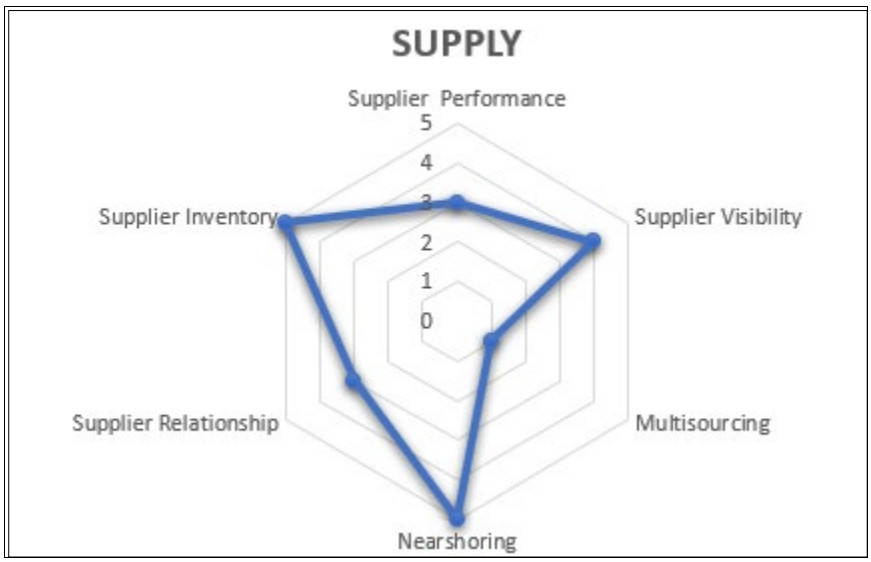

Figure 3. An example of resilience score for the six elements in the supply category of a hypothetical firm

Beyond the assessment and visualization of each pillar, the assessment tool can then calculate the average score of each category and then produce another radar chart (as shown in Figure 4) to demonstrate the organization's resilience performance along the seven pillars defined in our assessment, as well some of the other over-arching practices. Again, this can help the executive level to identify business domains that are most exposed to disruptions and subsequently decide which domains may be ripe for resilience-related investment.

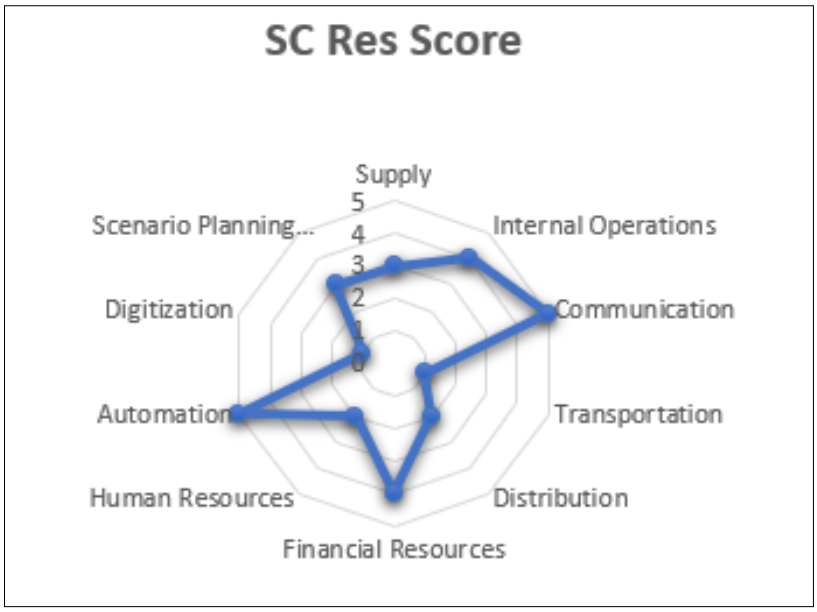

Figure 4. An example of a hypothetical firm of a cumulative score of major categories of supply chain disruptions and other over-arching practices that contribute to SC Resilience.

Note that our self-assessment tool does not distinguish between the categories, or the sub-categories to that end, and the final spiderweb graph simply associates equal weight to all entries. Clearly, the assessment can be amended to assign different weight to different practices (but this is up to the assessor).

7. Concluding remarks

This paper stemmed from an industry- and country-wide need to assess degrees of resilience of organizations and industry branches. Specifically, it had a clear objective: how to identify vulnerabilities of organizations and subsequently spot domains of resilience for investment by those entities, and possibly with governmental support. As a first step, the definitions of resilience were revisited, which led to the realisation that an adjustment of common definitions was desired. In particular, this work proposes to include the what (is resilience), rather than the how (is something resilient), while embedding the concept of measurement. This shall be essentially, and ideally, measured along the degree of impact, the duration of the impact, and the post-event performance, which reflects organizational learning. Resilience is then redefined as the degree to which an organization (or a supply chain) is impacted—either negatively or positively—by an internal or external disruption, the duration of the organizational distress and time to recover, and ultimately its post-disruption condition—whether it ends up in a better or worse long-term state.

To facilitate resilience measurement, domains of impact were studied, and, following Caniato and Rice (2003), this work uses their 7 pillars of the firm. A comprehensive review of the literature resulted with mapping of practices for resilience to these 7 pillars, while identifying another over-arching domain, which is delegated to the executive level. The list of resilience practices was developed

for a full assessment, generally following a scale from 1-5 to allow organizations to measure their performance, visualize, spot vulnerabilities, and identify domains for improvements.

The assessment tool created reflects a comprehensive approach to measuring degrees of resilience. As mentioned earlier, resilience is a multi-faceted and highly relevant and topical concept, and more work lies ahead to enable full assessment of resilience. For instance, measuring the degree of internal learning—as a proxy of the post-disruption state—and the duration of the impact require further exploration.

Our self-assessment tool was (partially) validated with a major stake-holder from the health sector. The stakeholder positively indicated the clarity, simplicity, and usefulness of the tool to identify weak areas in their supply chain and helped guide discussion on where to focus their subsequent resilience steps. In particular, as part of the broader project's objectives, a dashboard and an app continued to be developed, with a pilot demonstration for the same stakeholder from the health sector.

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Appendix

The complete assessment including the diverse categories for each of the dimensions are provided in the following table.

SUPPLY					
	1	**2**	**3**	**4**	**5**
Supplier Performance	No supplier data is recorded.	Supplier data maintained but no performance was analyzed.	We analyze to define KPIs and identify risks.	We share data on KPI with suppliers.	We collaboratively work with suppliers to develop plans and methodologies to mitigate and resolve disruptions.
Supplier Visibility	No supplier data is recorded.	We maintain data only for our primary suppliers.	We maintain records for suppliers for our primary suppliers as deep-tier suppliers.	We assess risks associated with our deep-tier suppliers.	We work in collaboration with our primary suppliers and their deep-tier suppliers for a risk-free resilient supply design.
Multi-sourcing	We work with our primary suppliers with no plans to replace them in disruptions.	We look for an alternative supplier only once a primary supplier is disrupted.	We have identified alternative suppliers for our products and services.	We have pre-approved alternative suppliers for our products and services.	We identify risks associated with pre-approved suppliers to facilitate resilient choices when needed.
Nearshoring	No nearshore suppliers have been identified.	Nearshore suppliers are identified but not yet qualified.	Nearshore suppliers are already onboarded and supported to develop their products in compliance with company standards (i.e. qualified).	We already procure products and services from nearshore suppliers whenever possible.	We also work collaboratively with suppliers to focus on nearshoring their productions and services.

Supplier Relationship	No supplier relationship plans in place	Informal relations with no long-term planning in place.	We have formal relations with some of our suppliers.	We have collaborative relationships with all suppliers for a mutual share of benefits and supply continuity.	We work with all of our suppliers to develop plans and methodologies for a resilient supply framework.
Supplier Inventory	We do not have any access to our suppliers' inventories.	We have limited access to our supplier inventory of products required for our organization but not enough to access risks.	We have access to our supplier's inventory data and their capacity which we use to access risks for our supply.	We share risk details for inventory with suppliers. We expect them to develop their resilient action plans.	We continuously cooperate with our suppliers to monitor their inventory levels for our requirements and assess their recovery times by simulating various disruptions in their inventory.

INTERNAL OPERATIONS OR PRODUCTION					
	1	**2**	**3**	**4**	**5**
Location flexibility	We do not have location flexibility (all operations are location specific).	We have identified alternative facility locations.	We have been operating our firm at more than one location but have not achieved operation uniformity across all locations.	We have achieved location flexibility for our organizational processes and services.	We continually review our location flexibility in terms of risks and disruptions. We also share our location planning with our suppliers and sales team so that they can plan the supply to facility and sales to market respectively.
Capacity flexibility	We operate on fixed capacity planning.	We are simulating capacity flexibility planning but it has not been operational yet	We have capacity flexibility for some of our operations and services.	Capacity flexibility is extended to all of the organizational operations.	We share our capacity flexibility planning with our supply and sales team so that we can be on the same scale for supply and demand.
Product Complexity	We have no measures to identify the degree of complexity.	We evaluate the degree of complexity.	We redesign our products in response to complexity.	We have process design for our products for reduced complexity.	We collaborate with our stakeholders to jointly simplify and standardize our products and their components.
Master Planning and Risk Assessment	We have no formal planning process in place.	We have informal master planning in place which is not reviewed or determined for risks.	Master planning in place for some of our products and services with an assessment of the risks associated.	Master planning and risk assessment in place for all of our products and services within the organization.	We share our master planning with our key stakeholders for them to review, prepare, and provide feedback on our master plan and the resilient framework we propose to develop.

COMMUNICATION					
	1	**2**	**3**	**4**	**5**
Interactions with stakeholders	Internal and external stakeholders not identified.	Internal stakeholders identified within the product line.	Key stakeholders are regularly informed.	Key and non-key stakeholders are regularly informed.	Key and non-key stakeholders are informed and actively engaged in planning processes.
Organizational Visibility	Our operations are limited to mails, fax, and spreadsheets for a data feed from operations.	We have identified the digital capabilities of our operations but have not moved all of the operations to the latest digital solutions.	Most of our operations are digital solutions.	All of our operations are on digital solutions.	We have integrated our digital solutions with our suppliers and service providers to ensure everyone is updated and has visibility across the operation flow.
Backup of Data and Parallel (Mirrored) IT system	We have no formal team in place to ensure data storage or parallel IT.	The only backup of information is limited to hard drive storage or cloud storage but not both within the organization.	Backup is maintained in hard drives and cloud storage for critical business-related information.	Backup of data is in place for all business and operations related to information records.	Data backup and parallel IT are in place.
Data Security	No formal team in place to ensure data security.	We have established some of the data security measures for information protection critical to our business.	All of our company operation information data security measures in place.	We also ensure data security measures are extended to our partners for their information critical to our business.	We are always equipped with the latest data security technologies and tactics for organizations, partners, and customer data.

TRANSPORTATION					
	1	**2**	**3**	**4**	**5**
Transportation Flexibility	We have limited logistics capabilities.	We have identified alternative modes and routes for our logistic movement to improve flexibility but they are not operational yet	Transportation flexibility for our operations is decided at the functional entity level.	Transportation flexibility decision for all of our operations is taken at the organizational level.	We continually review the flexibility in transportation to account for anticipated risks. We share such information with our suppliers and distributors.
Logistic Service Providers (LSPs)	We have not partnered with any LSPs for our logistics management.	The decision to involve LSPs is taken at the operational level and no data is maintained for their performances.	The decision for LSPs is taken at the organizational level, but information sharing is limited to inventory movement with no focus on risk identification.	Risks management in our supply or delivery with LSPs is maintained by LSPs.	We identify risks and develop resilient action plans in collaborations with our LSPs.
Warehousing flexibility	We are not aware of warehouse flexibility capabilities for the distribution of products.	We have warehouse facilities for our products. but no data is recorded to assess its flexibility.	We manage our warehouse with limited capacities and partial access to flexible capabilities.	We continually review critical products with the business to maintain flexibility in our warehouses for their storage and distribution.	We work in collaboration with our suppliers, production team, and sales team to understand product features and consumer demand to continually upgrade warehouse capabilities for a flexible operation.

Logistics Visibility	We currently do not focus on achieving logistics visibility.	Logistics visibility is limited to dispatching and receiving nodes.	We maintain logistics visibility for the movement of our transport and inventory but not risks and recovery plans.	We assess risks and recovery plans for our core products and services.	We also collaborate to track movements of transport and include inventories from our stakeholders.

DISTRIBUTION					
	1	**2**	**3**	**4**	**5**
Marketing	We do not have a formal marketing or sales team within the firm.	Our marketing team works independently without much interaction with the SC team.	Marketing and SC share products and information details over demand forecasts and supply.	The marketing-SC team share information and collaborate to identify risks and develop mitigation plans for products or services.	Our marketing team actively shares information and feedbacks with external stakeholders along with the firm SC team and consumers.
Packaging	We have no team or system in place to monitor and operate the packaging of our products and services.	We have informal teams who occasionally monitor packaging processes.	We have formal teams and systems in place to perform packaging operations for our products and services.	Our packaging team interacts with stakeholders in the organization to continuously evaluate and standardize the packaging process for product tracking and risk-free packaging of our products.	Our packaging team also involves external stakeholders such as suppliers, LSPs, or consumers for their feedback and improvement for our safe packaging and ensures effective tracking during disruptions.
Inventory Management	We do not keep/track of inventory for distribution of our products within our organization.	Inventory management is limited before the order. Once products are shipped, we do not track any updates on our inventory movement.	We manage inventory till delivery but we partially follow every defined resilience step.	We have integrated inventory management for our products and services with our partners to have a detailed overview of the risks and proactive recovery plans in place for a speedy recovery.	We have inventory management in place for all of our products and services. Live tracking, flow, and available stock data are shared with logistics, sales, and other concerned teams.

Customer Service	We have no formal customer service.	Customer service is limited to product warranty and service delivery.	We have limited options for customer feedback. Feedback is not recorded or used for further analysis.	We have options for customer feedback. Feedback is recorded and analyzed to improve our processes within the firm.	We have real-time options for customer feedback. Feedback is shared with relevant shareholders to align them with improvement plans.

FINANCIAL RESOURCES						
		1	**2**	**3**	**4**	**5**
Financial Reporting	***Short-term and long-term cash forecasting***	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after the disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.
	Pending debt or bond issuances for long-term cash position	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after the disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.
	Debt covenants	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after the disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.
	Receivables / credit losses	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after the disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.
	Hedging	We have not carried out this assessment.	We have a preliminary assessment of the impact.	We have completed the assessment on past financial impacts.	We have completed the assessment on past financial impacts and included future impacts in our reports.	Not applicable

	Assessment of business disruptions on the workforce from a financial perspective	We have not carried out this assessment.	We have a preliminary assessment of the impact.	We have completed the assessment on past financial impacts.	We have completed the assessment on past financial impacts and included future impacts in our reports.	Not applicable
	Assessment of business disruptions on inventory	We have not carried out this assessment.	We have a preliminary assessment of the impact.	We have completed the assessment on past financial impacts.	We have completed the assessment on past financial impacts and included future impacts in our reports.	Not applicable
	Scenario modeling for financial forecasting	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after the disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.
	Financial asset valuation	We have not carried out this assessment.	We have a preliminary assessment of the impact.	We have completed the assessment on past financial impacts.	We have completed the assessment on past financial impacts and included future impacts in our reports.	Not applicable
	Quarterly financial statement preparation and filing timeline	We have not carried out this assessment.	We have a preliminary assessment of the impact.	We have completed the assessment on past financial impacts.	We have completed the assessment on past financial impacts and included future impacts in our reports.	Not applicable
	Restructuring	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after a disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.

	Revenue recognition	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after a disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.
	Asset impairment	We do not use this report in our financial analysis of disruptions.	We use this report but it is not accessible to us soon after a disruption.	We create this report periodically and we include the impact of disruptions in this report.	We create this report immediately after disruption to assess risks and/or impacts.	We use this report to access past disruptions and also to simulate future impacts of potential disruptions.
Liquidity		We do not assess the liquidity data of our firm.	We are aware of liquidity in organizational performances but have not assessed the impact of risks on their performances.	We have initiated the impact of risks on organizational liquidity performances.	We have assessed the impact of risks on our current liquidity.	We have also practice in place to assess the impact of existing and potential risks on our current and future liquidity performances.
Insurance Policies		No insurance policy	We are entirely dependent on cash from sales for our operations.	Insurance policies are in place for core operations.	Insurance policy extends to all internal operations within the company.	We verify and regularly update insurance policies for our internal and external operations for suppliers and service providers.

HUMAN RESOURCES					
	1	**2**	**3**	**4**	**5**
Tracking workforce availability	We do not have processes or systems in place to track the location of our workforce	We have informal processes in place to track some, but not all of our workforces	We have processes and systems in place and can track most of our workforce	We have processes and systems in place to track all of our workforces	We have processes and systems in place to track all of our workforce as well as their skills and roles to the company's operations.
Business Continuity	We are not aware of business continuity plans related to our workforce.	We do not have defined business continuity plans in place related to our workforce	We have limited plans in place for employees that cover critical health and safety procedures. Those plans include clear definitions of when remote work should occur	We have business continuity plans in place to cover the most relevant health and safety policies for the majority of employees and contingent workers. Remote working policy goes beyond eligibility to address access constraints	We have comprehensive business continuity plans in place that cover the vast majority of foreseeable considerations for health, safety, and productive remote working
Skill Mapping and workload sharing	No alternative resource management	We have some plans to develop alternatives for loss of workforce, but no initiation has been done for it yet	We have already been practicing some of the backup plans for our workforce but have not achieved them on a full scale yet	We have full-scale backup plans such as cross-training and automation etc. for our workforce.	We have also identified key stakeholders and assisted them with our solutions and technologies to help them with their and our business continuity.

OVERARCHING PRACTICES					
	1	**2**	**3**	**4**	**5**
Risk Mapping	No risk identification processes in place.	Informal risk identification is in place at the business entity level.	We have risk identification processes at the business entity level but this is not recorded at the organization level.	Risk identification is maintained at the organization level for all identified core operations	We keep records of the risks and vulnerabilities of our core and non-core operations.
Digitization	Our operations are limited to mails, fax, and spreadsheets for a data feed from operations.	Core operations are identified to be moved to digital solutions.	Core operations are on digital solutions.	All of our operations are managed digitally at the functional level.	All of our operations are integrated across the supply chain internally with all functional units and externally with materials and service providers.
Automation	---	We have not yet identified the core operations of our organizations and corresponding automation capabilities available in the market	Our digital capabilities are automated and we are identifying core operations and their automation capabilities.	We have identified and automated our core capabilities within the firm.	We have expanded automation to all of our operations as well as keep track of the latest automation methodologies which we can incorporate in our operations.
Scenario Planning (War Game, What Ifs)	We do not practice scenario planning in our supply chain design.	We have informal planning processes but they are at a functional level, not a business level.	We have scenario planning teams for identified core operations.	We have scenario planning for all of our operations.	We have developed scenario planning for our operations, our suppliers, financial advisors, and every other stakeholder across the business.