VIEWPOINT PAPER

THE CASE FOR VALUE CHAIN RESILIENCE

THE RESILIENCE SHIFT

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ABOUT THE RESILIENCE SHIFT

The Resilience Shift exists to inspire and empower a global community to make the world safer through resilient infrastructure. More people than ever depend on the critical infrastructure systems that provide essential energy, water, transport and communications services, and underpin food, healthcare and education. When this infrastructure fails the consequences can be catastrophic.

Supported by Lloyd's Register Foundation and Arup, the Resilience Shift provides knowledge and tools for those responsible for planning, financing, designing, delivering, operating and maintaining critical infrastructure systems. Our aim is to ensure infrastructure systems are able to withstand, adapt to, and recover quickly from anticipated or unexpected shocks and stresses - now and in the future.

DEFINING RESILIENCE

Resilience is the ability to withstand, adapt to changing conditions, and recover positively from shocks and stresses. Resilient infrastructure will therefore be able to continue to provide essential services, due to its ability to withstand, adapt and recover positively from whatever shocks and stresses it may face now and in the future.

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ABSTRACT

PURPOSE

Value chain analyses that help businesses build competitive advantage must include considerations of unpredictable shocks and stressors that can create costly business disruptions. Enriching value chain analysis with considerations of system resilience, meaning the ability to recover and adapt after adverse events, can reduce the imposed costs of such disruptions.

DESIGN/METHODOLOGY/APPROACH

The paper provides a perspective on resilience as both an expansion and complement of risk analysis. It examines applications of both concepts within current value chain literature and within supply chain literature that may inform potential directions or pitfalls for future value chain investigations. Established frameworks from the broader field of resilience research are proposed for value chain resilience analysis and practice.

FINDINGS

The synthesis reveals a need to expand value chain resilience analysis to incorporate phases of system disruption. Current explorations in the literature lack an explicit acknowledgement and understanding of system-level effects related to interconnectedness. The quantification methods proposed for value chain resilience analysis address these gaps.

ORIGINALITY/VALUE

Using broader resilience conceptualizations, this paper introduces the resilience matrix and three-tiered resilience assessment that can be applied within value chain analyses to better safeguard long-term business feasibility despite a context of increasing threats.

KEYWORDS

Value chain, Resilience, Risk assessment, Supply chain

INTRODUCTION

The ‘Fourth Industrial Revolution’, termed Industry 4.0 (Lasi et al., 2014) has produced unprecedented degrees of automation and connected business operations through cyber-physical networks. While this increasing interconnection and interdependence between organizations provides opportunities to improve value chains, it also exposes businesses to a level of risk that is arguably the highest since the Second World War (Calatayud and Ketterer, 2016). Information technology can enhance lean operations to ensure efficiency and cut costs, but such configurations provide little margin for error during disruption. Network reliability and resilience is therefore a crucial design concern for business operations in a world subjected to unpredictable disruptions.

History repeatedly demonstrates that unpredictable disruptions can affect the production, capital, and marketing upon which businesses rely. Disruptions can arise from extreme weather, longer-term climate change, declining international order, economic crises, changing societal priorities, cyber threats or terrorism (World Economic Forum, 2019), or the international outbreak of a deadly disease such as COVID-19 (McKinsey and Company, 2020a). The business impacts from such threats have been increasing since early 2000, with insurance claims for business interruptions associated with infrastructure-related disaster management changing from 25% of total insurance losses to almost 50% (Zurich Services, 2019). In the emerging case of COVID-19, many business interruption insurance policies have exclusions for communicable diseases (Travelers.com, 2020), weakening claims for insurance reimbursements, a critical source of resilience and potentially compounding already dire predictions for economic recovery (McKinsey and Company, 2020b).

Risks, defined as a product of threat, vulnerability and consequence (National Research Council, 1983), can unfold across business operations. Current risk analysis, comprising risk assessment and management, is predominantly asset-focused. Risk assessments identify vulnerabilities in a system’s components and subsequently strive to harden specific assets and prevent interruptions to system functionality. Risk-based management relies on anticipating known and predictable threats, but has proven insufficient and potentially prohibitively costly in managing less known or unpredictable events (Bostick et al., 2018). Pettit et al. (2019) argue that risk analysis for business focuses primarily on discrete events rather than the build-up of gradual chronic stresses. Risk analysis alone inadequately serves a changing interconnected world, in contrast to a more holistic system-focused perspective which yields richer insights for planners and managers (Linkov and Trump, 2019; Pettit et al., 2019).

This paper explores the complementary concept of resilience and its utility in the value chain context. While risk assessment quantifies both the potential vulnerability and threat associated with specific scenarios to estimate risk and direct efforts to prevent its realization, resilience emphasizes recovery and adaptation. Resilience research calls derive from the significant business impacts from shocks (e.g. extreme weather or viral pandemic) and stressors (e.g. aging infrastructure). These shocks and stressors decrease cumulative value generation across the business cycle despite business expenditure and value investment. Integrating resilience within value chain analyses is vital given the increasing threats, complexity and interconnectedness of most critical infrastructure systems, and the many stakeholders who can influence business operational feasibility. Value chain analysis using a resilience lens will reveal actions that support, enhanced or decrease resilience and will help decision makers achieve value chain management objectives and reduce the costsimposed costs by disruptions when they occur.

This paper argues that existing approaches for resilience quantification can be applied within value chain analysis to better safeguard business feasibility despite disruptions. The literature on resilience applications for business contexts is growing, but considerable confusion remains about its role and implementation in practice. Supply chain management has incorporated risk management and more recently resilience, but such an extension has not occurred to any significant degree within value chain management. To support the discussion on resilience in business value chains, this paper will:

- review the evolution of value chains as systems grow more interconnected and complex;
- connect the concept of resilience, introduced above, with value chain frameworks in theory and practice;
- review the literature on supply and value chain risk and resilience to understand current trends and gaps for value chain resilience; and
- synthesize existing methods of resilience operationalization and quantification for applications to value chain analysis.

The paper progression is shown in **Figure 1**.

VALUE CHAIN ANALYSES: EVOLUTION AND CURRENT CHALLENGES

A business value chain envisions a system formed of subsystems that each have inputs, transformation processes, and outputs that deliver value (Porter, 1985). Business requires multiple suppliers and processes to create value, therefore supply chains form part of the overall value chain where supply and demand drive operational relationships across the production cycle (Cox, 1999; Adobor, 2019). A value chain describes the full range of activities required to bring a product or service from conception, through the different phases of production that comprise physical transformation, input of various producer services, delivery to consumers and disposal after use (Kaplinsky and Morris, 2001; Calatayud and Ketterer, 2016). **Figure 2** shows the notional value chain for a project life cycle and the value augmentations as a project moves through different phases.

Value chains do not exist in the sense of having a tangible reality, but are instead a framework for stakeholder interactions and system operations. While supply chains emphasize the needs for supplies and suppliers to deliver goods or services, value chains study where value is, or how it can be created or lost before the desired service is delivered or used. From organizational and supply chain perspectives, value can include additional performance metrics such as sustainability and resilience (Govindan et al., 2015).

FIGURE 1

Article structure

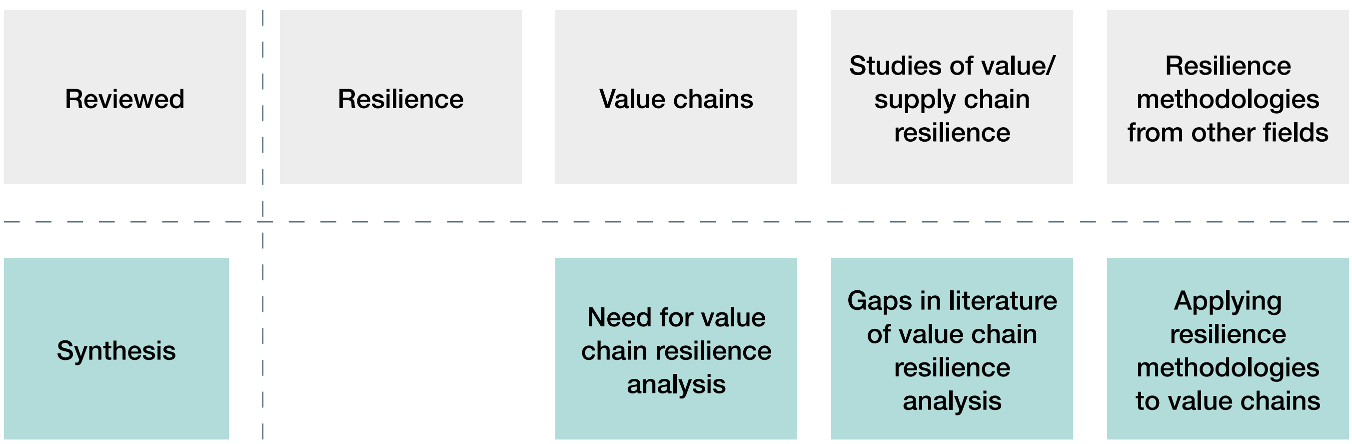
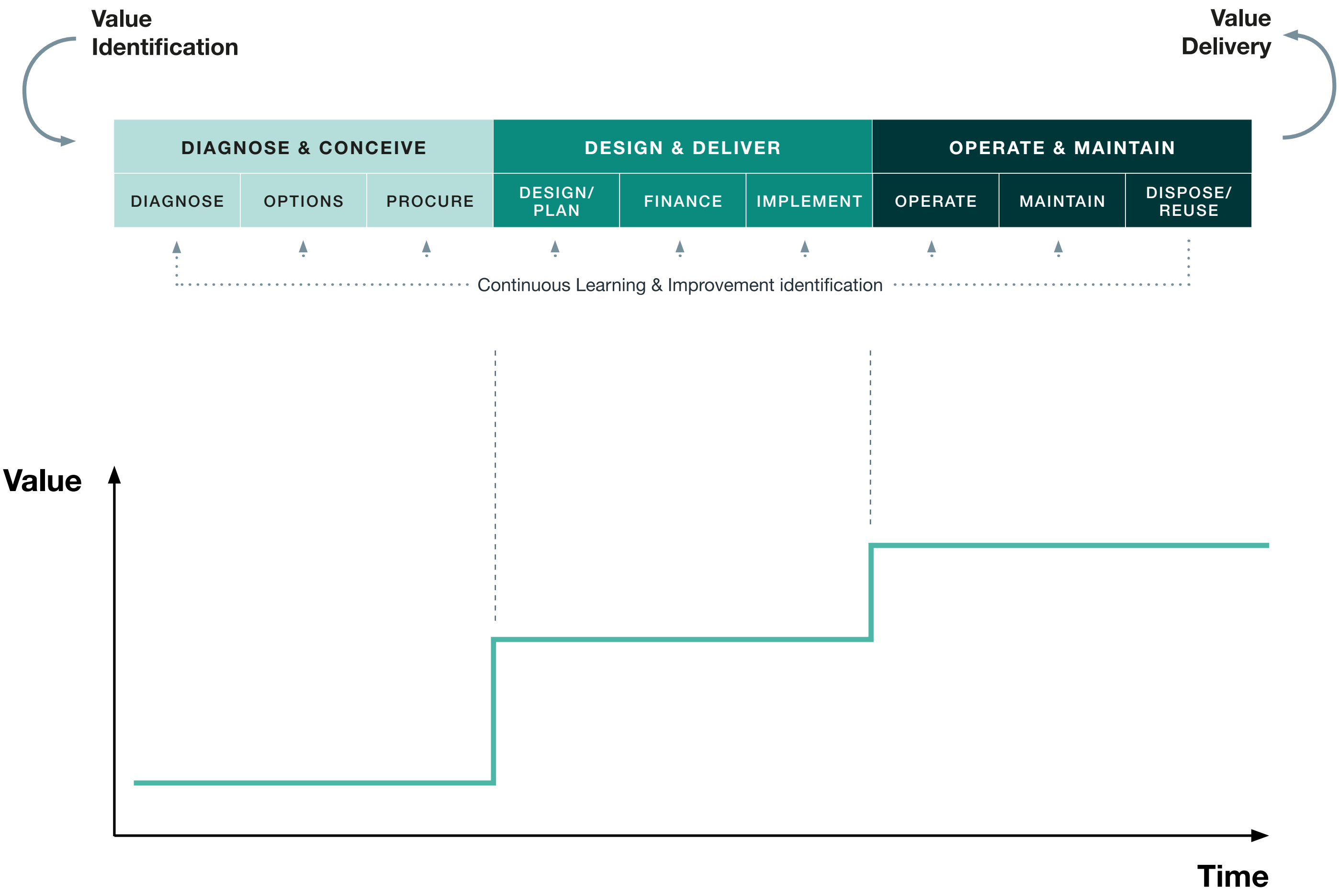


FIGURE 2

Notional value chain over time for a general project life cycle



Value chains integrate more social and information networks with all their complexity, interconnectedness and interdependencies across multiple stakeholders. Previous applications of value chains have included increasing commercial profits, improving the competitiveness of localities, alongside reducing poverty (Kaplinsky and Morris, 2001).

Since the initial framing by Porter (1985), the value chain concept and its analysis have significantly evolved. In its beginnings, value chain analysis focused on the manufacturing sector to help establish competitive advantages (Porter, 1985). By identifying the value chain component that would most benefit from change, business profitability could improve. The concept was largely linear, with a set of sequential activities augmented by supporting activities and applied to one entity at a time.

However, current trends of globalization, digitalization and demographic changes all promote broader system-based approaches in practice (CGMA, 2014; McWilliam et al., 2019). The concept of value has evolved to incorporate traditional operational strategy metrics such as cost, flexibility, quality and time (Hayes and

Wheelwright, 1984). Additional value dimensions can increase the complexity of management, and recent advances that include business and broader performance valuations are incorporated in the concept of shared value (Porter and Kramer, 2011). Value chains can be used to help structure organizations, so that all individuals working on elements of the value chain work in close proximity or have a shared understanding of the wider system (Knaster and Leffingwell, 2017).

Value chain analyses can build strategic competitive advantages, including identifying management alternatives that maximize shareholder value and ensure sustainable value creation (Kaplinsky and Morris, 2001). A value chain reveals a business system's connections and their potential to be affected by shocks and stressors (IDB, 2016). Companies using value chain analysis have increased efficiency and earned higher revenues by reducing costs and accelerating the time and the magnitude of value delivery (Nauhria et al., 2018; Savino et al., 2015).

Most stakeholders oversee only specific domains within a larger value chain, but their value production management decisions should not seek to maximize their own benefits without examining other impacts on the system. For example, Ford would have likely gained market shares if General Motors and Chrysler had collapsed during the 2008 economic crisis, but because the negative impacts for their shared suppliers and dealers could have extended to Ford's own value chain, Ford joined its rivals in lobbying the US Government for their financial support (Acemoglu et al., 2012). Currently, both the Organization for Economic Cooperation and Development (2019) (OECD) and World Economic Forum (2010) discuss global value chains, where individual businesses are part of complex systems of interconnected value chains with completely different challenges and opportunities.

The World Economic Forum (2017) argues that Industry 4.0 has created a new value chain whose specific drivers include:

- Open innovation as companies involve their customers and other companies in innovation and development processes;
- Distributed manufacturing that decentralizes production structures and upends classic manufacturing paradigms; and
- New collaboration models between companies, primarily horizontally, but also vertically.

These changes must be implemented into value chain analyses in ways that do not inadvertently increase vulnerability to disruptions. As shocks and stressors become more complex and systems provide more entry points, both risk and resilience analyses will need to understand the system as a sum of many interdependent parts.

RESILIENCE IN VALUE CHAINS

Value chains may have efficiency at component or subsystem levels and perhaps structurally embedded inefficiencies at the global and system level. A resilience assessment can reveal the benefits of inefficiencies such as unused capacity that may be crucially important during periods of disruptions. In this way, a resilience analysis can protect and encourage broader system value creation and delivery even in the face of adverse circumstances.

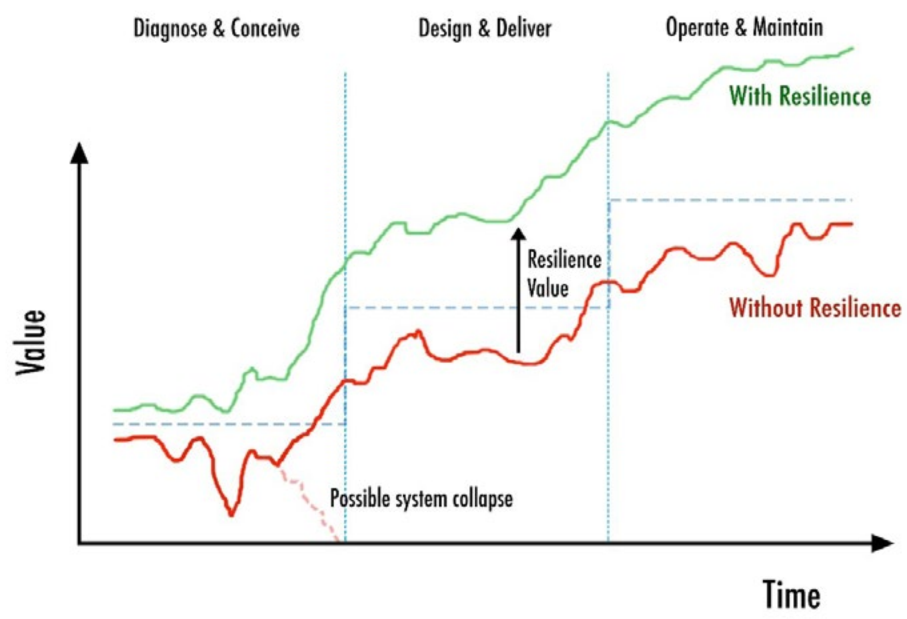
Examining resilience requires a new methodological framing that expands beyond traditional risk assessment. Resilience analysis enables planning system responses to disruptions that occur despite risk management efforts. Significant shocks can cause the complete collapse of non-resilient value chains (**Figure 3**: red curve). Conversely, a resilient value chain can sustain a growth trajectory despite shocks and stressors (**Figure 3:** green curve). Even though slowdowns result from these disruptions, their impacts on cumulative value are far less pronounced than for non-resilient value chains.

Resilience can be defined as a network property of complex systems (Linkov and Trump, 2019) where the connections between systems components, especially those that can assume critical functions during adversity, define overall system resilience. In a business context, the critical function is delivering value to customers and stakeholders. Following a disruption, a business' ability to perform this function requires efficient recovery, and the temporal patterns of such recovery are crucial to business viability. Methodologically, assessing system resilience requires demarcating thresholds below which functionality is impossible and anticipating the system's ability to adapt by learning from past experiences (Linkov and Trump, 2019). System memory and adaptive management are required to better prepare for potential future disruptive events (Tidball et al., 2010).

Despite the need for risk, resilience and value chain analyses to support business operations, their integration at a methodological level may undermine the strengths of each approach. Value chains are broadly conceived and their possible disruptions are difficult to define in advance, hindering implementing risk-based approaches. However, direct analysis of resilience is possible and compelling in the value chain context. Resilience is particularly important for complex systems with many avenues for potential disruption, with high uncertainty, and hence ill-suited for risk modeling (Hohenstein et al., 2015; Klibi et al., 2010).

FIGURE 3

Illustrative example of value generation under shocks and stressors



The National Academy of Sciences defined resilience as “the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events” (National Research Council, 2012). Organizations and governments are increasingly applying this four-stage definition as foundation for resilience assessment and management (Executive Office of the President, 2013; Larkin et al., 2015; Linkov et al., 2014; Linkov and Palma-Oliveira, 2017; National Research Council, 2012; Office of the Press Secretary, 2013).

The National Research Council’s phases of resilience reflect temporal patterns in system response to adverse events. The **planning phase** encompasses the ability to predict potential shocks and stresses to the infrastructure and identify mitigation strategies that can be implemented before an adverse event occurs. This phase is related to threat identification in traditional risk management. However, a resilience-based planning approach not only does limit itself to preventing risks but also imagines their impacts during the subsequent phases, absorption, recovery and adaptation.

The **absorption** phase of resilience is also connected to risk assessment and related concepts which seek to absorb threats while avoiding or minimizing system damage (e.g. robustness in supply chains in Klibi et al., 2010). Compared to traditional risk management approaches, a resilience-based absorption phase considers recovery and emergence of unknown unknowns associated with low probability and longer-term stresses (Linkov et al., 2018).

Only resilience-based management examines the **recovery phase** which returns a system's critical functions to an acceptable or enhanced level following an adverse event (Fahimnia et al., 2018). Resilience fundamentally provides the groundwork for a "soft landing" and expeditious recovery that help the targeted system both avoid undue loss and rebound quickly and efficiently. The system's ability to recover important functions through different means or system self-reconfigurations may inform the tools designed to model and enhance system resilience.

Finally, **adaptation** assesses the new means of system performance by identifying lessons learnt from events impacting the infrastructure systems and by informing future resilience assessment and mitigations (i.e. the "Plan" phase).

Consideration of these phases can inform planning decisions as well as reaction decisions as disruptions unfold. While the first two phases overlap with risk management, the novelty of resilience involves enhancing system capacity for recovery and adaptation. This can produce improvements in many sectors, including, for example, the critical infrastructure sectors of energy and transportation (Mian et al., 2020). There is great opportunity for resilience conceptualization to contribute to value chain analysis by examining the systemic business consequences of a product, process or service that fulfils a valuable economic or social function becomes unavailable and the consequences and choices over different phases of the disruption.

CONNECTING RISK, RESILIENCE AND SUPPLY CHAINS TO VALUE CHAIN: A REVIEW

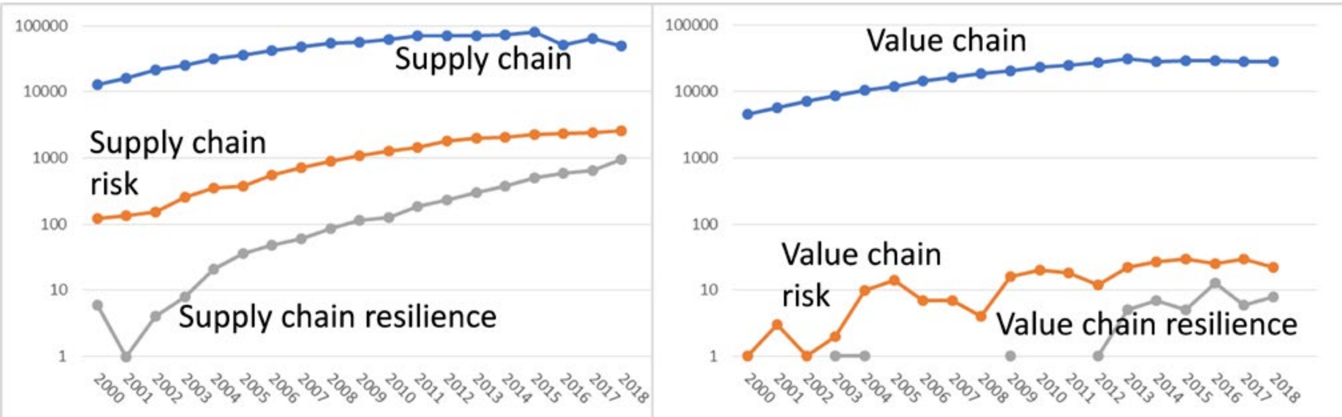
As value chain resilience is a novel concept closely connected to the notions of risk and supply chain, this section presents the evolution of value chain resilience in comparison and in contrast to the concepts of supply chain and risk. Notable papers in the fields of supply chains and value chains are discussed in relation to value chain resilience.

The literature review was conducted using Google Scholar and Web of Science databases using search queries "supply chain" and "value chain" combined with "risk" and "resilience" as keywords. Risk and resilience have been extensively applied to supply chains. The percentage of supply chain papers that mention "risk" has grown from less than 1%in 2000- 2003 to about 5% in 2018. Resilience in a supply chain context has been the subject of various studies, resulting in several review papers (Pettit et al., 2019) and the overall number of publications has grown significantly, from less than ten papers per year (in 2000-2004) to 941 papers in 2018 alone (Figure 4). **Figure 4** shows the growth of these topics over time according to Google Scholar.

Figure 4 also shows that there is a marginally lower volume of value chain literature compared to supply chain literature. However, significantly fewer value chain publications focus on risk: annually published papers on value chain risk have

FIGURE 4

Illustrative example of value generation under shocks and stressors



not risen above double digits. The value chain resilience work that emerged in 2012 has an annual output of single digits (Figure 4). Despite the larger quantity of articles examining supply chain resilience, there are weaknesses in these studies that may inform the emerging field of value chain resilience. These include challenges in understanding the principles of risk and how the differ from resilience, as well as a lack of quantitative measurements or processes to evaluate resilience.

The field of supply chain management typically focuses on the physical domain of systems, with literature predominantly related to risk. Often only one component of the risk triplet is examined – threat, vulnerability, consequence – typically with limited connection with other components or broader issues (Mersky et al., 2020). For example, the World Economic Forum tracks emerging global threats, including cyber-attacks, natural disasters and extreme weather events (World Economic Forum, 2017). Calatayud and Ketterer (2016) proposed a taxonomy of risks affecting value chains, including systemic, market, operational, credit and liquidity. However, discussion of specific assessment methods and tools is lacking in their report. Managing supply chain risks can produce supply chains that are hardened against specific predictable events, but can fail when faced with unpredicted or unpredictable scenarios (Hohenstein et al., 2015; Klibi et al., 2010). These scenarios require supply chain resilience to support recovery from the disruptions that could not be prevented or predicted.

Modeling resilience requires understanding network interconnectivities, however, most supply chain literature models only portions of the supply chain (Choi and Wu, 2009). A large portion of the supply chain resilience literature reviewed in Mersky et al. (2020) considered disruptions from failures of individual actors, not failures in inter-actor connectivity. General considerations of network connectivity (e.g. transportation) in a supply chain context are rarely explored. Nearly half of all the papers covered in Mersky et al. (2020) ignore the possibility that transportation route segments could be shared by different links and therefore be jointly disrupted. Only 12% explicitly acknowledge supply chain assets as being connected to each other via a separate and unified transportation network. Most supply chain disruptions are considered random events, while the potential for targeted disruptions into supply chains presents a significant gap, given the increasing adversarial threats posed to disrupt supply chains. Overall, viewing disruptions in the context of the system-of-systems is rare and requires further study.

The supply chain literature offers viewpoints on resilience. Klibi et al. (2010, 2012) argue that optimizing supply chain efficiency in times without disruption limits the overall value that a supply chain brings to business. While Klibi et al. (2010) discuss a generic methodology, Sprecher et al. (2015) and Gardner and Colwill (2018) provide specific recommendations to make the supply chain of critical manufacturing materials more resilient; assessment tools are also discussed. Finally, Collier et al. (2017) consider supply chain resilience in the context of biofuels and provide overall recommendations on value chain resilience.

In supply chain management, most disruptions are frequent and identifiable. As a result, mitigating those disruptions through a focus on supply chain risk forms a significant proportion of the extant supply chain literature. A narrower focus on supply chain resilience has emerged from risk management, borne from potential disruptions that are large enough to substantially reduce production capability for a significant period. In such cases, resilience efforts can reduce potential loss across the absorption, recovery and adaptation phases.

The deficiencies of supply chain risk assessment and management are only magnified when considering the value chain. Though some reports include calls for value chain resilience, most grey – non-academic – literature focuses on highlighting the overall importance of resilience without providing specific recommendations. Concept delineation may prove an obstacle: despite an article title about “improving value chain resilience”, Gardner and Colwill (2018) frame their discussion around risk and in terms of processes often characteristic of supply chains.

Several think tanks and consulting companies have proposed value chain resilience tools in different application domains (for example, Revolution Advisors, 2013; Deloitte Touche Tohmatsu Limited and Forbes Insights, 2016; APEC, 2015). Early papers examining value chain resilience advocate for more stakeholder and community support but do not provide depth on resilience meanings or its connection to value chains (Lowitt et al., 2015; Tallontire et al., 2015). Value chain resilience has been applied to agricultural/food system management. For example, transforming value chains can be a first step in supporting climate resilient economic development (Ludi et al., 2019). Vroegindewey and Hodbod (2018) used concepts of socio-ecological resilience to conceptualize value chain resilience for food systems. The authors proposed seven resilience-enhancing principles and recommend a qualitative resilience assessment framework developed by resilience alliance. Doherty et al. (2019) echo the conclusions of Vroegindewey and Hodbod (2018) on the relevance of socioecological resilience, but note that the framing emphasizes systems rather than actors, with implications for stakeholder health and wellbeing. Doherty et al. (2019) highlight the complex nature of value chains and call for a comprehensive research agenda for resilient food systems. Aboah et al. (2019) identified elements of resilience and specific metrics relevant to tropical agriculture value chains.

Continuing the field of agricultural value chain resilience, McIntyre et al. (2019) identified resilience and adaptability as supporting attributes in agribusiness value creation. Canevari-Luzardo (2019a) examines the relationship between the value system network structure and agribusiness's ability to adapt to climate change and emphasizes a resilient system's ability to enhance the adaptive capacity of its actors. Finally, Olafsdottir et al. (2018) reports on the VALUMICS project for value chains modeling in food systems with the explicit goal of resilience quantification. This latter paper outlines the project structure and goals and provides overall framing, and specific applications are expected in the future.

In the mining sector, Lim-Camacho et al. (2019) advocate for a whole-of-value chain approach, with considerations of diminishing returns of responses to multiple or compounding disruptions. The mining industry occupies a delicate position in climate related resilience analysis because it produces the emissions that exacerbate climate change. However, climate mitigation is not the same as resilience to climate impacts. Where public and mining sectors overlap, value chains centered on sustainability priorities can modernize economies and support future growth (Sekar et al., 2019a). While Sekar et al. (2019a) provide framework for such green growth, the measures to promote the changes remain topics for subsequent research. The methodology for value chain analysis for the mining industry is detailed in Sekar et al. (2019b) and involves analysis of each subsector's value chains to prioritize beneficial initiatives.

The value chain literature demonstrates that if an activity is an important part of the value chain, then the various types of links relating the activity should be reinforced. Resilience concepts apply to social and economic systems and an analogy can be drawn between the relationships of supply chains to resilience and value chains to resilience. The role of social components must be incorporated, such as Ludi et al. (2019)'s incorporation of gender, to fully understand and anticipate impacts. However, the value chain resilience literature – and to some extent supply chain resilience literature – lacks an explicit acknowledgement and understanding of system-level effects related to interconnectedness of systems and domains.

The fact that a value chain can encompass a network of activities and associated links invites established methods of systems thinking and specifically network science analysis to address value chain resilience. Nevertheless, we found that the value chain literature (and to some extent the supply chain) on resilience demonstrates a lack of explicit acknowledgement and understanding of system-level effects related to interconnectedness.

Expanding the scholarship of value chain resilience to other fields is warranted, including impacts of disruption beyond climate. Over two orders of magnitude more studies are published referencing **supply chain resilience** compared with **value chain resilience**. Practitioners have applied supply chain resilience to relevant production systems, but the more abstract representation of value chains has not lent itself so readily to resilience analysis and quantification. Value chain resilience provides the same utility to the field of value chains as supply chain resilience for the field of supply chains. Thus, operationalizing value chain resilience is needed.

METHODOLOGIES FOR OPERATIONALIZING RESILIENCE OF VALUE CHAINS

Previous conceptualizations of resilience in other fields provide a starting point for operationalizing it for value chain analysis. These conceptualizations include metrics and model-based approaches for resilience quantification that can be applied within value chain analyses to better safeguard business feasibility despite a context of increasing threats. The resilience matrix (Linkov et al., 2014) can be adapted for value chain resilience by combining the four temporal phases of resilience with four key business application domains: physical, cyber, cognitive and social, which are defined in **Table 1**. **Figure 5** shows the interactions between these domains and business value chains.

The **physical domain** is where events take place and are perceived by sensors and individuals. It is broadly defined as inclusive of both man-made (e.g. infrastructure and processes) and natural (e.g. ecological) environments. Data and knowledge emerging from the physical domain is transmitted through and stored in the cyber domain that constitutes much of the information about supply and value chains. In the **cognitive domain**, sensemaking and decisions are made for the **social domain**. These domains link value chains to the business and social realities of specific products. Within the domains, resilience can build the ability of business to recover and adapt to disruption while continuing to bring value to stakeholders.

Figure 6 (Linkov and Kott, 2019) shows two primary approaches for resilience assessment currently described in the broader resilience literature that can be applied for value chains. Metric-based approaches use measures of individual properties of system components or functions to assess overall system performance. In general, metrics are defined as distinct system properties that quantify the degree to which the system objectives are being achieved. Metrics provide vital information pertaining to a given system through analysing attributes of that system. Model-based approaches use system configuration modeling and scenario analysis to predict system evolution and emergent properties. Modelbased approaches strive to represent real world dynamism through specific mathematical framing and require knowledge of the system's mission, critical functions, temporal patterns, thresholds, memory and adaptation.

Methodologically, the multiple approaches to measure system resilience can be classified using the three-tiered framework proposed by Linkov et al. (2018):

- **Tier I:** Identifies the critical functions that a system provides and prioritizes their performance both during and following a disruptive event. Analytically, Tier I uses existing data, expert judgment and conceptual models.
- **Tier II:** Characterizes the system's process model or critical path model, it identifies sequential and parallel events in a disturbance that can create feedback and dependencies that are the root of cascading system failures.
- **Tier III:** Models critical functions and related subsystems where each process and each component of the system is parameterized.

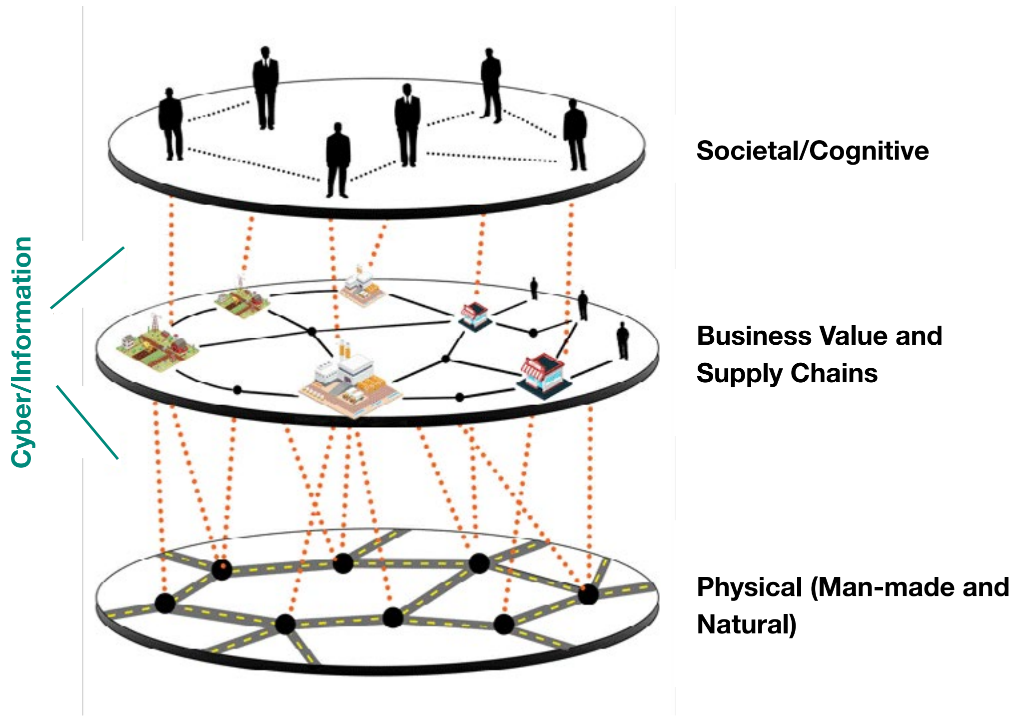
TABLE 1

Definition of resilience domains in business
Source: Linkov and Trump (2019)

DOMAIN	DESCRIPTION	EXAMPLE
Physical	Physical infrastructure and natural environment, including structure, processes and design	Man-made: roads, buildings, infrastructure, power lines, Natural: ecosystems, ecological systems, environmental media
Cyber	Information and information development about the physical domain.	Monitoring data, models, databases, communication networks
Cognitive	Use of the information and physical domains as well as organisational structure and communication for decision making.	Decision-maker values and organizational missions
Social	Placing decisions in the context of societal needs and values	Social networks, stakeholder groups and community values, organizational missions

FIGURE 5

Value chains operating within systemdomains

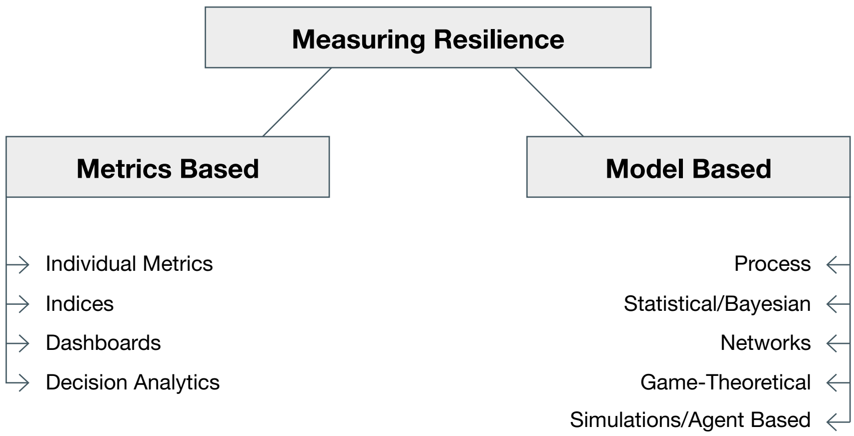


The tiered framework allows analysts to select resilience assessment and decision support tools to inform associated management actions relative to the scope and urgency of the risk and management opportunities for improving system resilience. The resilience evaluation can conclude at any tier when enough information has been synthesized to identify actionable system investments to improve system resilience under available resource constraints.

Impacts of the COVID-19 pandemic have revealed vulnerabilities for value chain resilience. Global shelter-in-place orders, with exceptions for essential workers, have demonstrated the disruptions that arise when the locations of value production change. With many variations on both metrics and realization of success, teaching institutions moved entirely online, while offices where remote work is possible are conducting work and meetings online. For some institutions, success has been underpinned by preparation in the weeks preceding stay-at-home orders, such as test runs of online transitions. Other challenges have been addressed as they arise, such as limitation in VPN connection capacity. Meanwhile, value production at on-site locations has greatly changed as many minimum-wage workers such as grocery store clerks and food pickers have been deemed essential workers that cannot fully isolate. Where these workers' new risks have not been compensated with hazard pay, conflicts have emerged. Similarly, as workers become infected with the virus but are not eligible for sick leave, this causes further worker-management conflicts and also risks worsening the pandemic as sick employees continuing to work may expose co-workers or customers. The organizational structure of many companies did not consider pandemics in their value chain. These organizations may sustain more damage than necessary and take more time to recover. More time is needed to fully understand the impact of these shifts on other aspects of the economy, as well as COVID-19 stresses on interconnected systems, like availability of equipment to support medical staff treating patients.

FIGURE 6

Metric-based and model-based approaches for Resilience Assessment. Multiple tools have been developed to address resilience in systems in both methodological groups
Source: Linkov and Kott (2019)



CONCLUSION

This paper discusses applying resilience across the value chain to support economic recovery for businesses and society after disruptions. It provides frameworks to connect resilience with the business value chain, which will enable the development of tools to assess resilience value for businesses with significant operating areas.

This paper synthesizes literature relating supply chain and value chain resilience, as well as the most relevant resilience management frameworks, to recommend avenues to promote building value chain resilience. The literature on value chain (and to some extent the supply chain) resilience demonstrates a lack of explicit acknowledgement and understanding of system-level effects related to interconnectedness, which will be necessary for transforming value chains to be more resilient. Practitioners have applied supply chain resilience to relevant production systems, but the more abstract representation of value chains has not lent itself so readily to resilience analysis and quantification. Applying a resilience lens will support a broader assessment of business impacts relative to the benefits through a project life cycle. This paper provides a perspective of broader resilience theory literature to propose methods for applying resilience to value chains as a further protection of business feasibility as disruptions emerge. Value chain analysis allows businesses to develop an holistic systems view of their operations and to identify the critical interdependencies that could significantly impact company revenue if exacerbated by shocks and stresses. Beyond revenue, such disruptions could affect societal structures dependent on specific provisions or services, as seen in the COVID-19 crisis. Which businesses will recover, and the extent of their recovery encompass a critical piece of current economic discussions, and outcomes will be influenced by value chain resilience.

The potential difference in value achieved between resilient and non-resilient systems can justify investments to build system resilience. Connecting resilience to value chain analysis can bolster corporations, industry and whole economies against an array of potentially serious shocks and longer-term stresses and their imposed costs. The unpredictable can occur, such as a global viral pandemic, and where risk management cannot provide protection, resilience will support recovery. Emerging principles and methods for resilience management have transferable application to value chains. The field of supply chain management can benefit from understanding resilience in value streams to enhance the overall performance of complex and interconnected networks that constitutes globalized value chains. The emergence of COVID-19 revealed vulnerabilities of modern value chains. Not only is the time ripe for discourse and development along these lines, the time is now critical.

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