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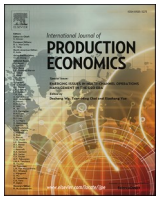

Are we truly ready for what is coming? A reflection on supply chain resilience in face of megatrends

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ABSTRACT

Supply chains (SCs) have increasingly faced major disruptive events that defy existing management approaches, affecting their processes in both the short and long term. Current megatrends (e.g., digital transformation, aging population, growing urbanization, shifts in consumer demands, geopolitical tension, depletion of natural resources, climate change) have impacted organizations, requiring managers to rethink the foundational assumptions and develop new capabilities to obtain more resilient SCs. In this study, we analyse the readiness of SCs for coping with disruptions caused by seven megatrends. Based on extensive debates among the authors and supported by a narrative literature review, we framed this analysis according to four potentials of resilient systems (monitoring, anticipation, responding, and learning) and three types of SC structure (linear, networked, and hub-and-spoke). We debated and pooled our viewpoints to identify readiness levels for coping with each megatrend, which allowed the formulation of research propositions to be further investigated. Overall, the readiness of all resilience potentials varies across megatrends and SC structures, although the potentials to anticipate, respond and learn seem to be less developed (either lowly or moderately ready) than monitoring, especially when considering disruptions caused by changing demographics and climate change. Further, linear SCs appear to be more vulnerable to most megatrends. Finally, we outline opportunities for further investigation regarding SCs resilience to megatrends' disruptions.

1. Introduction

Supply chains (SCs) are complex logistics systems that comprehend individuals, organizations, resources, activities, and technology to convert raw materials into finished goods and distribute them up to the end consumers (Stevenson and Spring 2007; Stock and Boyer, 2009). SCs vary in terms of the number and diversity of tiers and players, vertical integration, industry sectors, level of collaboration and transparency, among other characteristics. Moreover, there has been a shift in competition from a company-versus-company mode to SC-versus-SC form, which adds to the complexity of SCs management (Kopczak and Johnson, 2003; Lejeune and Yakova, 2005; Machuca et al., 2021). Hence, literature on theories and practices to support supply chain management (SCM) and achieve higher operational performance results has grown over the past decades (e.g., Davis, 1993; Tan et al., 2002; Gomm, 2010; Sanders, 2020).

At the same time, SCs have increasingly faced major disruptive events that defy existing management approaches, affecting SC processes in both the short and long terms (Craighead et al., 2007; Katsaliaki et al., 2022). These disruptions stem from unforeseen or unplanned events or situations that affect the flow of goods, information, or services (Browning et al., 2023), on both the supply and demand sides, exposing organizations to operational and financial issues (Snyder et al., 2016). Exemplar severe disruptive events that strongly affected SCs are the

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9/11 terrorist attack (Bueno-Solano and Cedillo-Campos, 2014), the 2008 Great Recession (Revilla and Saenz, 2017), the 2011 earthquake and the tsunami in Japan (Matsuo, 2015), the health scares around the Ebola virus in 2013–2016 (Sumo, 2019), SARS in 2002–2003 (McCormack et al., 2008), and the COVID-19 pandemic (Ivanov, 2020). As such, these arise from the external environment, being related to natural disasters, global health pandemics, political uncertainty, economic upheaval, cyber and terrorist attacks, supplier threats, or rapid swings in consumer preferences and demand, for instance (Chopra and Sodhi, 2014; Ambulkar et al., 2015). These events have shown the vulnerability of the SC, giving visibility to concealed inefficiencies in procurement, distribution and inventory management, inadequate contingency plans, lack of collaboration between SC partners, and inadequate demand forecasting (Patrucco et al., 2023). The implications of disruptive events also fluctuate in terms of severity, duration, or focus, with implications unevenly distributed across SC tiers and actors (Tortorella et al., 2022a).

Resilient performance is crucial to cope with these disruptions, referring to the ability of a SC to persist, adapt, or transform in the face of change (Ponomarov and Holcomb, 2009; Wieland and Durach, 2021). Studies on SC resilience have significantly increased (Tortorella et al., 2022b), reflecting a growth in the complexity of contemporary societies. In parallel, governments and policymakers have encouraged new solutions to increase SC resilience. For instance, Australia, India, and Japan developed an international collaboration initiative to promote best practice SC policy and principles in the Indo-Pacific (Australian Government, 2021). Despite the continued efforts of researchers and practitioners, the severe impacts of recent major disruptions suggest a lack of preparedness of SCs (Rungtusanatham and Johnston, 2022; Nikookar and Yanadori, 2022). As new disruptive events emerge (or known ones affect SCs thought to be protected from them), it becomes clear that lessons from previous ones have not been learned (Sodhi et al., 2023; US Bank, 2024). This drawback is understandable as every major disruption has unique characteristics both in itself and in terms of its interactions with the environment.

This issue is aggravated when current megatrends change the SCs landscape (Pessot et al., 2023). Such megatrends have a major impact on organizations, requiring managers to rethink the foundational assumptions of SCs design (Rajesh, 2017; Kalaitzi et al., 2021). In addition, new capabilities, not yet mature in most SCs, may be needed to favour resilience development (Brusset and Teller, 2017; Agarwal et al., 2021). Reasons for such unpreparedness may be related to both theory and practice. In theoretical terms, a significant part of the SCM research has focused on controllability, rationality, optimality, and objectivity, hindering the overcoming of multifaceted challenges and fostering the development of solutions unfit for purpose as they downplay SC complexity (Darby et al., 2019; Wieland, 2021). From a practical standpoint, research evidence and industry reports suggest that some of the existing organizational strategies might undermine resilience in the SC. For instance, an over-emphasis on firm resilience as if it was independent from SC resilience (Sá et al., 2020), taking a reactive position due to short-term cost avoidance and budgetary goals (Elluru et al., 2019), and lack of alignment between industry needs and government efforts (Chen et al., 2013). Although these strategies might generate immediate benefits, they tend to be isolated and lack a systemic view of the SC. Hence, they can conflict with the interests of the SC, and lead to a less resilient SC. These issues raise concerns about whether SCs are truly ready to deal with the disruptions originating from megatrends, which are gathering pace and unfolding concurrently.

This paper addresses this drawback by exploring the relationship between SC resilience and megatrends through debate, advocacy, and refutation (MacInnis, 2011). We reflect on the existing initiatives for developing SC resilience from both theoretical and practical perspectives and how they can cope with disruptions caused by the megatrends (Frias et al., 2023; Pessot et al., 2023) in different SC typologies. Such a debate has been conducted from the resilience engineering (RE) standpoint (Hollnagel et al., 2006; Hollnagel, 2014, 2017), which preconizes that resilient systems must display four main potentials: (*i*) monitoring, (*ii*) anticipation, (*iii*) responding, and (*iv*) learning. These four potentials are interrelated and all necessary for a resilient system, even though their relative importance is context-dependent (Hollnagel, 2017).

In contrast to the perception of SCs as an engineerable technical system and static-shape components (Wieland and Durach, 2021), RE provides a socio-technical view of resilience (Righi et al., 2015) aligned with the characteristics of most disruptive events, as they tend to affect both social and technical components of SCs. Furthermore, RE concepts have been widely used to frame resilience in Operations and SCM studies (e.g., Salehi et al., 2020; Hosseini et al., 2020; Tortorella et al., 2022c), also indicating the validity of these four potentials to structure our discussion. Due to the size of the existing literature, which undermines a comprehensive and structured review, a narrative review was carried out, leading to the outline of future research opportunities.

2. Supply chain resilience

As SCs become larger and more interconnected, they also tend to be more vulnerable to disruptions typically associated with high-complex systems such as those stemming from non-linear interactions characterized by disproportionality between causes and effects (Chopra and Sodhi, 2014; Durach et al., 2017). Only in the first half of 2018, for instance, more than 300 out of the 1069 reported disruptions directly affected the continuity of SCs (Resilinc, 2018). According to Pettit et al. (2019), two main factors contribute to the increase in the number of SC disruptions. First, globalization of both procurement and distribution amplifies the geographical reach of SCs and the consequent opportunities for disruptions linked to climate change, making SCs more complex and brittle. Such globalization is also commonly associated with outsourcing and dependence on a small number of suppliers, while policies to significantly reduce inventory have decreased SCs' flexibility (Revilla and Saenz, 2017). Second, the existing risk management approaches have demonstrated poor capacity to foster SC resilience. The complex nature of SCs demands constant monitoring and imagination to identify vulnerabilities and agility to respond to unplanned disruptions. Therefore, resilience development needs both new analytical techniques and new mental models (Marley et al., 2014; Ivanov, 2021).

Resilience allows SCs to anticipate, adapt, respond, and recover promptly from unexpected disruptions (Ponomarov and Holcomb, 2009; Sá et al., 2020). A resilient SC is expected to absorb disruptions, restore and recover its operations while keeping its competitiveness (Chopra and Sodhi, 2014). However, various definitions of SC resilience are found in the literature, each one with its own limitations. For instance, from the engineering point of view, resilience is the organizational ability to respond and recover normal operations after a disruption occurs (Carpenter et al., 2001). Wieland and Durach (2021) add that resilient organizations should move to an enhanced condition after disruptions. This latter view of resilience is aligned with the concepts of ecological systems, claiming that the SCs should adapt and change to new operating conditions rather than remain in a rigid state. Although such an interpretation is commonly implicit, some researchers (e.g., Wieland, 2021; Wiedmer et al., 2021) have adopted this definition. Hollnagel (2016) considered that the resilience definition has been changing to expand the conceptual approach. It is defined as a resilient system "if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions". Therefore, the emphasis is on making the SC perform as needed in a variety of conditions and not just recover from stresses and threats. A review of different definitions of resilience along prior research can be found in several systematic literature reviews (e.g., Al Naimi et al., 2022; Tukamuhabwa et al., 2015; Shishodia et al., 2023).

An important further conceptualization is related to the links

between the concepts of resilience and robustness, which are similar but may have different meanings depending on the context. Resilience focuses on self-organization, learning, and prevention, being often measured by how quickly a system can recover to its original state of performance (Ponomarov and Holcomb, 2009; Wieland and Durach, 2021). Robustness is proactive (emphasizing systemic functionality) and corresponds to the ability to maintain performance when dealing with internal or external disruptions (Clement et al., 2021). The ability to maintain, cope, and withstand refers to robustness, whereas the ability to recover or bounce back is about resilience (Munoz et al., 2022). Both robustness and resilience are desirable characteristics of a SC, but their importance may rely on the organization and the context. For instance, if a SC is shorter and less likely to be impacted by major global disruptions, robustness might be more important. In turn, high levels of robustness might imply greater operational costs, impairing the competitiveness of SCs (Mackay et al., 2020). Woods (2015) also added that a resilient system tends to be robust, but the opposite may not be true.

Regarding SC resilience measures, literature has been prolific, and a diversity of complementary (and sometimes conflicting) alternatives has been observed. For example, Pettit et al. (2010) identified 7 vulnerability factors and 14 capability factors, arguing that resilience is achieved when the proper balance between vulnerability and capability is obtained. Soni et al. (2014) quantified resilience using a single numerical index that combined 10 interrelated SC resilience enablers. Similarly, Hosseini et al. (2020) proposed a measure for SC resilience utilizing the Bayesian network approach with a compounding function of vulnerability and recoverability, testing it in an open-system context of a manufacturer. Behzadi et al. (2020) introduced a new measure for SC resilience called the net present value of the loss of profit, which integrated many facets of time, cost, and the level of recovery in SCs.

As for supportive measures of SC resilience, Tang (2006) listed nine strategies when major disruptions hit: postponement, strategic stock, flexible supply base, make-and-buy, economical supply incentives, flexible transportation, revenue management, dynamic assortment planning, and silent product rollover. Marley et al. (2014) approached these measures more abstractly, arguing for reducing interactive complexity to mitigate such disruptions. Sheffi (2020) discussed the trade-offs that must be considered to manage supply shortfalls, leading to some countermeasures such as favoring the most important customers, maximizing short-term revenues, shaping demand, altering products, and taking care of the vulnerable. Other strategies include collaboration among SC partners, development of redundant suppliers, capacity slack, establishment of pool demand, balancing in-house production and outsourcing, and the integration of new information and communication technologies (Wieland and Wallenburg, 2013; Scholten and Schilder, 2015; Narayanamurthy and Tortorella, 2021).

When considering the RE view, resilience is seen as managing the trade-off between efficiency and thoroughness (Hollnagel, 2011; Nemeth and Herrera, 2015). Given the scarcity of resources and uncertainty typically found in complex environments, such as SCs, systems are continuously adapting their performance and adjusting goals to cope with societal and market demands. This means a resilient system must focus on efficiency or thoroughness according to the circumstances (Hollnagel et al., 2006; Hollnagel, 2014, 2017). Resilient systems (e.g., SCs) display four main potentials, which are all necessary. They have already been empirically examined in various studies on SC resilience (e.g., Righi et al., 2015; Salehi et al., 2020; Tortorella et al., 2022c), which suggests their utility and validity, and justifies our choice. They are defined below and are adopted to frame our discussion of SC resilience.

i) Monitoring: represents knowing what to focus on so that it does not become a threat in the future. The monitoring should encompass the system's performance and what occurs in it;
ii) Anticipation: refers to knowing what to expect, allowing to anticipate developments further in the future;
iii) Responding: knowing what to do by adjusting the current mode of functioning to regular or irregular changes, disturbances, and opportunities; and
iv) Learning: refers to knowing what has happened in past successes and failures, taking lessons from the experiences.

3. Supply chain typology

SCs vary according to different aspects such as structure, function, and industry sector, among other characteristics (Meyr and Stadtler, 2014). The types of SCs determine how quickly and efficiently goods and/or services reach their destination (Birhanu et al., 2014). According to Fisher (1997), SCs may be categorized as being either efficient or responsive. The former implies a cost minimization orientation, whereas the latter prioritizes customers' needs regardless of costs. An efficient SC is recommended for products that have a more stable demand, longer life cycle and lead times, and lower variety (a.k.a. functional products); in opposition, responsive SCs are indicated for innovative products with contrary characteristics (Pérez-Franco et al., 2016). However, such an exact match may not always be evidenced (Lo and Power, 2010).

With regards to the operating models, SCs might be categorized into six groups depending on the business goals and nature of the products. The most traditional is the continuous flow model, which excels for waste minimization and efficiency maximization typically found in settings with stable supply and demand (e.g., commodities) (Christopher and Ryals, 1999). The fast chain model prioritizes speed and agility, being well-suited for businesses with short-lifecycle products (Camargo et al., 2020). The efficient chain model emphasizes efficient inventory management and getting the most out of production workers and equipment. It is adequate for mass-scale, highly competitive markets in which keeping a competitive edge demands greater efficiency in delivery (Fahimnia et al., 2017). The agile model, suitable for made-to-order businesses, allows the rapid adaptation to demand changes by maintaining a jointly managed inventory among suppliers and customers, utilizing collaborative product design, and coordinating the entire SC (Van Hoek et al., 2001). The flexible model, adequate for businesses with marked seasonal demand, integrates components from the agile and efficient models, allowing adaptation to change while assessing cost-benefit. It generally encompasses a broad supplier base, with some suppliers chosen for speed and others for cost-efficiency (Malik et al., 2023). The last mode, custom-configured, merges principles from continuous flow and agile models, allowing the customization of products' configuration as they are produced. Although materials for the non-customizable components of the product must be provided at a constant rate, those for the personalized components may be supplied at variable rates (Salvador et al., 2004).

In terms of structure, the SC typology affects its complexity, generating, among others, differences in transactions and processes along the SC, intensity of dependencies between suppliers and customers, and volume of exchanges (Manuj and Sahin, 2011). In general terms, the different and multiples connections between SC partners impact on the level of SC complexity, which needs to be addressed (Garrido-Vega et al., 2023). It will be necessary to establish effective management to address both the structure complexity (related to the number and variety of links in the SC) and the dynamic or operational complexity (related to the interactions between SC members) (Bode and Wagner, 2015). Although there are many ways to classify SCs (Gualandris et al., 2021), three types stand out. Linear SCs are characterized by a straightforward, sequential flow of products from suppliers to manufacturers, then distributors, retailers and, finally, to customers (Hazen et al., 2021). It is usually easier to manage, although disruptions at one link tend to impact the whole SC (Gurbuz et al., 2023). Industry sectors that typically adopt a linear SC structure are clothing, and food and beverage. In networked SCs (e.g., automotive, technology, and electronics), multiple interconnected entities are involved, resulting in more flexibility and collaboration across many SC players as products and information flow

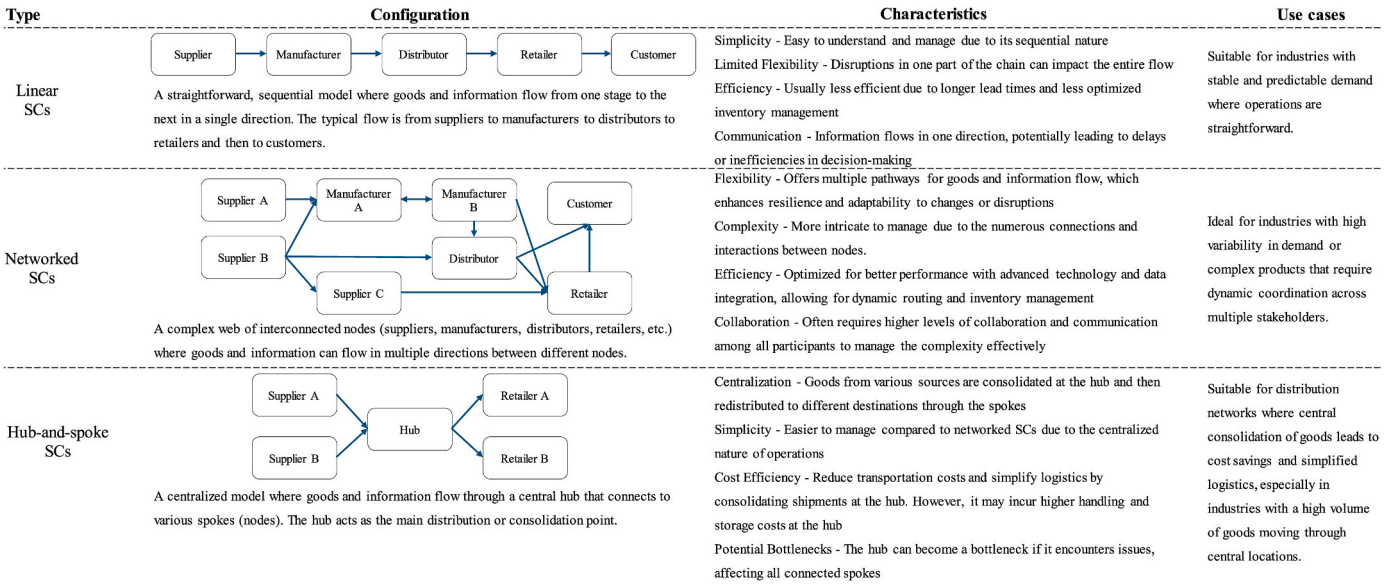

Fig. 1. – Characteristics of different SC structures.

in several directions (Wang et al., 2018). Lastly, hub-and-spoke SCs are usually centralized around a hub (e.g., distribution center) that links to many spokes (e.g., suppliers or retailers), enabling efficient distribution and management (Liu et al., 2022). This structure is commonly found in industries such as transportation and logistics, retail, and e-commerce. As structure implicitly refers to the interconnectedness, efficiency, and thoroughness of SCs, which are foundational elements in the complexity-informed RE view (Hollnagel, 2017), we adopted this classification in our conceptual debate (see Fig. 1).

4. Supply chain megatrends

Conceptualized by Naisbitt (1982), megatrends are major movements at a global scale prone to have a relevant and broad impact on society, ecology, and the economy. They are comprised of mutually dependent trends that establish a guiding force that affects how organizations and SCs interact (Bash et al., 2023; Frias et al., 2023). Megatrends entail a global structural change in almost all industry sectors, influencing technologies of products and processes, human labor, management, and resources (Rajesh, 2017; Kalaitzi et al., 2021; Tortorella et al., 2021). Hence, they are disruptive forces in the global economy, impacting current and future market competitiveness by driving innovation processes and redefining business models. This raises the need for awareness of global megatrends and their evolution, allowing the identification of new paths of growth and development (Gajdzik et al., 2021; Institute for the Future, 2022).

Indications about megatrends vary according to certain aspects, such as time, industry sector, and socioeconomic contexts. For instance, in 2013, the report "Emerging Trends in Global Manufacturing Industries" (López-Gómez et al., 2013) was published by the University of Cambridge's Institute for Manufacturing in collaboration with the United Nations Industrial Development Organization (UNIDO) suggesting eight megatrends. In 2017 it was revisited to add another six (López-Gómez et al., 2017). Westkämper (2014) proposed eight megatrends expected to influence the strategic development of the European manufacturing industry towards the 2030 vision: aging of population, individualism and customization, knowledge in information and communication technology (ICT), globalization of the manufacturing ecosystem, high level of urbanization, sustainability of products, processes, and services, turbulent finance markets, and public debt of State. Similarly, in Australian Government (2021) suggested guidelines for a 20-year development horizon of its industry, identifying five global megatrends. More recently, Pessot et al. (2023) considered six megatrends as contingencies to understand how digital technologies should boost SCs' capabilities. Table 1 consolidates the main megatrends cited in the literature.

Despite the different designations and lack of consensus on how they are defined, research on megatrends continues to receive attention, and they have frequently been used to anticipate future disruptive events (Naughtin et al., 2024). SCs must consider the movements from these

Table 1
– Relevant megatrends cited in literature.

Megatrend	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
Natural resources depletion	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	19
Changing demographics	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	16
Changing consumer habits/demands	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓		✓	✓		✓	16
Urbanization	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓		✓	✓	✓		✓	15
Digital transformation	✓			✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	15
Climate change	✓	✓					✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	14
Geopolitical tension	✓	✓	✓	✓			✓	✓			✓	✓	✓			✓	✓	✓		✓	13
Globalization	✓	✓	✓	✓			✓				✓	✓	✓	✓	✓	✓				✓	12
National industrial policies	✓	✓	✓	✓			✓	✓				✓	✓		✓	✓				✓	11
Accelerating production life cycles	✓	✓	✓		✓		✓			✓		✓				✓				✓	9
Glocalization/reshoring						✓	✓					✓			✓	✓				✓	6

Authors: 1-Bowersox et al. (2000); 2-Oner et al. (2007); 3-López-Gómez et al. (2013); 4-Westkämper (2014); 5-CSIRO (2016); 6-López-Gómez et al. (2017); 7-Galińska (2018); 8-Berger (2020); 9-United Nations (2020); 10-Tortorella et al. (2021); 11-Gajdzik et al. (2021); 12-Agarwal et al. (2021); 13-Kalaitzi et al. (2021); 14-Frias et al. (2023); 15-Hauge, 2023; 16-Bash et al. (2023); 17-Pessot et al. (2023); 18-Bojovic and McGregor (2023); 19-Capurro et al. (2024); 20-Naughtin et al. (2024).

Table 2
– Readiness analysis of SCs resilience to megatrends.

Megatrend	SC structure	Monitoring	Anticipation	Responding	Learning
Changing consumer habits	Linear SCs	High	High	Low	Low
	Networked SCs	High	High	High	High
	Hub-and-spoke SCs	High	High	High	High
Urbanization	Linear SCs	High	Moderate	Moderate	Moderate
	Networked SCs	High	Moderate	Moderate	Moderate
	Hub-and-spoke SCs	High	High	High	High
Digital transformation	Linear SCs	High	Low	Moderate	High
	Networked SCs	High	Moderate	Moderate	High
	Hub-and-spoke SCs	High	Moderate	Moderate	High
Changing demographics	Linear SCs	Moderate	Moderate	Moderate	Moderate
	Networked SCs	Moderate	Low	Low	Low
	Hub-and-spoke SCs	Moderate	Low	Low	Low
Geopolitical tension	Linear SCs	Moderate	Moderate	Moderate	Moderate
	Networked SCs	Moderate	High	High	High
	Hub-and-spoke SCs	Moderate	High	High	High
Natural resources depletion	Linear SCs	Low	Low	Low	Low
	Networked SCs	High	High	High	High
	Hub-and-spoke SCs	Moderate	Moderate	Moderate	Moderate
Climate change	Linear SCs	High	Low	Low	Low
	Networked SCs	High	Moderate	Moderate	Moderate
	Hub-and-spoke SCs	High	Moderate	Moderate	Moderate

changing conditions to successfully align their strategies and develop the necessary abilities to maintain and improve performance (Simangunsong et al., 2012). Overall, most of the investigated literature on megatrends (see Table 1) indicates movements on (*i*) changing consumer habits, representing the greater customization requirements; (*ii*) urbanization, symbolizing the increase in global population living in urban areas; (*iii*) digital transformation, indicating the integration of novel digital technologies into businesses and societies transforming the way-of-work; (*iv*) demographic change, which refers to the aging population; (*v*) geopolitical tension, denoting the growth of nationalism, separatisms, terrorist attacks, and border security enforcements; (*vi*) natural resources depletion, which is represented by the scarcity of natural resources due to indiscriminate use in industry; and (*vii*) climate change, which denotes the natural disasters caused by global temperature increase. The seven megatrends used in our work, in addition to being fairly well cited by other works (Table 1), derived from the combination of indications from Kalaitzi et al. (2021) and Pessot et al. (2023), allowing us to frame our discussion on SC resilience.

5. Discussion

Utilizing insights from literature (presented in sections 2, 3, and 4), and our practical and academic expertise (each author has more than 20 years of experience in supply chain management), we now reflect on SCs' readiness to monitor, anticipate, respond, and learn from each one of the seven megatrends proposed by Kalaitzi et al. (2021) and Pessot et al. (2023). SCs are analysed according to their three main structure types previously presented (i.e., linear, networked, hub-and-spoke). A summary of these analysis is shown in Table 2. Based on extensive debates among the authors and supported by the narrative literature review, we defined readiness levels (low, moderate, or high) depending on the reports observed in the literature and the empirical evidence experienced by the authors. Although the assignment of the proposed SC readiness levels was initially performed by each author individually, we debated and pooled our viewpoints to identify readiness levels for coping with each megatrend. Whenever a consensus was not reached over the debate, the predominant position of the authors was utilized to fill out Table 2; as there was an odd number of authors, a tie was not possible. Below, we present the rationale used to assess each readiness level.

5.1. Changing consumer habits

Most SCs, regardless of their structure, usually present effective mechanisms to deal with the *changing consumer habits* megatrend either through marketing analysis and consumption forecast, or customer experience tracking (Briedis et al., 2020; Hennequin et al., 2023). For example, a leading online retailer may use real-time data analytics to adapt its inventory and promotional strategies, reflecting immediate changes in consumer preferences, especially noticeable during holiday seasons or flash sales. Networked and hub-and-spoke SCs are more likely to effectively share information on consumer habits shift across all tiers, owing to their fuzzy and multilateral communication (Wang and Hu, 2020). Linear SCs are also capable of properly monitoring and anticipating end consumers' shifts in preferences, especially first-tier organizations (Pirc Barčić et al., 2021). Nevertheless, due to more sequential, hierarchical relationships, communication inertia of linear SCs tends to be greater than the other two structures, where information flows more freely (Wang et al., 2018), the ability to respond and learn from this trend is likely to be lower. Particularly in hub-and-spoke SCs, ineffective but well-connected hubs have the potential to cascade down inaccurate information on consumer habits to the whole system in unpredictable ways (Liu et al., 2022). Nevertheless, given the most frequent hub-and-spoke SC scenarios, we still considered a high level of learning readiness in Table 2.

5.2. Urbanization

According to ESPAS – European Strategy and Policy Analysis System (2019) and United Nations (2020), by 2030, the world is expected to have 43 megacities (majority in developing economies) and, by 2050, two-thirds of the population will live in urban areas. The growing density of urban areas raises the need for SCs to enhance their connection to urban points, improving, for instance, last-mile transportation and just-in-time distribution (Galińska, 2018; Gajdzik et al., 2021). A practical example is the deployment of urban micro-fulfillment centers which decrease delivery times and emissions by situating inventory closer to end consumers, particularly effective in cities like New York and Tokyo. Focusing on what is critical or may become a threat in the short term (i.e., monitoring) may not be an issue to SCs, as knowledge of this megatrend is well established. Nevertheless, learning and responding to its implications might be increasingly difficult for SCs characterized by very large distances between production and end consumer (Pessot et al., 2023), which is usually the case for linear and

networked SCs. In opposition, hub-and-spoke SCs are prone to better cope with the challenges imposed by this megatrend, as their central hub acts as a focal point for inventory management and distribution facilitating transportation and reducing costs (Sindhwani et al., 2023). A similar readiness level may be observed for the learning potential in these SCs, since it intrinsically depends on how SCs deal with disruptions originated by this megatrend.

5.3. Digital transformation

The optimization of SCs' operations through advances in data capture and analytics has been on the top of strategic planning for many companies (CSIRO - Commonwealth Scientific and Industrial Research Organisation, 2016; Capurro et al., 2024). However, most organizations and SCs still struggle to grasp the true benefits and challenges of digitalization (Gajdzik et al., 2021). For instance, the adoption of Internet-of-Things in a networked SC structure can provide real-time tracking of goods and predictive maintenance for equipment, enhancing responsiveness but also exposing the SC to cyber-physical systems vulnerabilities. Additionally, the adoption of novel digital technologies has allowed the emergence of new business models (Bash et al., 2023), disrupting the existing "ways-of-working" in many SCs and raising uncertainty among managers and organizations. Thus, although SCs are aware of this megatrend, their ability to anticipate threats and opportunities and respond to them is relatively limited and shortsighted. Since digital transformation is more frequently associated with high value-added SCs (Tortorella et al., 2021), this megatrend can be particularly detrimental to resilience in linear SCs, which tend to be commonly adopted for commodities (Christopher and Ryals, 1999). Linear SCs have a structure that does not enable high or medium anticipation of digital transformation but does allow for moderate responding supported by a high learning capacity. The ability to learn from the disruptions caused by this megatrend seems to be independent of the SC structure, implying greater readiness for learning.

5.4. Changing demographics

The population over 65 years-old is expected to reach 1.5 billion by 2050 (United Nations, 2020), raising the necessity for a lifelong learning mindset for senior workers. This impacts the social responsibility of SCs, as they will have to adopt business practices that support the well-being of an aging workforce (Pessot et al., 2023). Some examples can be found in global manufacturing firms that have adjusted their ergonomic standards and introduced flexible working hours to accommodate an aging workforce, particularly in their European and Japanese facilities. Highly complex SCs (e.g., networked and hub-and-spoke) may have more difficulties with developing human-centered initiatives than traditional SCs (e.g., linear SCs), as they usually present a larger number and wider diversity of players (Tortorella et al., 2022a), in addition to diversified organizational contexts and human resources policies (Brandao and Godinho Filho, 2024). Nevertheless, SCs' readiness for this megatrend may be an issue (either low or moderate readiness level) for all resilience potentials, regardless of the structure. This suggests the existence of a systemic problem on the way SCs have developed and trained their workforce.

5.5. Geopolitical tension

The growth in nationalism, separatisms, terrorist attacks, and border security enforcements have raised geopolitical tension (Berger, 2020). For instance, a European SC restructured its logistics network after Brexit to mitigate customs delays and tariff impacts, diversifying its supplier base across other EU countries and Turkey. Additionally, new geographical and economic disputes and barriers among nations and regions (e.g., the Ukraine war, and China and Taiwan tensions) have been impacting SCs' operations (Bojovic and McGregor, 2023). This restricts trades, affecting sourcing decisions, logistics and manufacturing operations, and risk management (Pessot et al., 2023). Although the monitoring capacity is relatively limited, SCs may be able to create strategies to anticipate certain situations, mitigating the impact of disruptions and more quickly responding to them. For instance, the development of multiple suppliers may reduce the risks associated with trade barriers, allowing to rapidly redefine feasible options for sourcing raw material and components (Browning et al., 2023). Hence, it becomes necessary to put efforts into the reconfiguration of SCs (Agarwal et al., 2021). These countermeasures may be more easily adopted by less rigidly structured and more collaborative SCs, such as networked and hub-and-spoke. Linear SCs, instead, tend to be linked to traditional structures and rely on long-term relationships (Narkhede et al., 2024), being more vulnerable to sudden changes caused by geopolitical crises. This structural issue, however, is less likely to impair learning from successes and failures generated by this megatrend.

5.6. Natural resources depletion

Scarcity of natural resources (e.g., water, food, and rare-earth elements) is predicted to affect a significant part of global population in the upcoming years (United Nations, 2020), negatively impacting sourcing decisions. A notable example involves automotive manufacturers integrating circular economy practices, such as recycling rare-earth elements from used vehicles, to lessen dependency on volatile global markets. ESPAS – European Strategy and Policy Analysis System (2019) forecasted an 1.7% increase per year in energy consumption, while Berger (2020) suggested that the availability of at least thirty different rare-earth elements (e.g., lithium and cobalt) will become critical. This megatrend requires SCs to be able to identify such criticalities and develop approaches to more efficiently utilize resources (Pessot et al., 2023). Since the perception of such a megatrend may be more sensitive to certain SC tiers (Krishnan et al., 2020; Ali et al., 2021), players at different tiers may not monitor and anticipate it as easily. This amplifies the need for information sharing, which is typically found in networked SCs (Malik et al., 2023). Although hub-and-spoke SCs also foster a more collaborative environment, these SCs are centered on the focal distribution hub, which can become an information-sharing bottleneck and impair a cross-tier monitoring. Similarly, linear SCs do not encourage a system-wide perception of issues across tiers, entailing a more reactive mode that may not always be timely (Jonsson et al., 2024). This not only undermines the agility with which linear and hub-and-spoke SCs respond to disruptive events originated by this megatrend but also jeopardizes learning, since SC players are likely to be consumed by firefighting activities instead of reflecting on what went wrong and adjusting their strategies for coping with future situations (Takeda-Berger et al., 2021).

5.7. Climate change

With the global temperature increase, natural hazards are expected to give rise to disasters more frequently (Bowersox et al., 2000; Berger, 2020). These may cause logistics and production management disruptions, pushing SCs to devise countermeasures that minimize such impacts (Kalaitzi et al., 2021). For example, some electronics manufacturers in Southeast Asia have redesigned their SCs by incorporating disaster-resistant infrastructure and strategic placement of warehouses away from high-risk areas, such as flood plains and earthquake-prone zones. This proactive approach includes enhanced collaboration with local authorities for real-time weather updates and disaster preparedness training for its staff. Because natural hazards (e.g., avalanches, droughts, floods, heat waves, tropical cyclones, wildfires, etc.) are phenomena oblivious to the structure of SCs, the ability to monitor this megatrend may predominantly rely on external players that are not directly connected to SCs (e.g., government and research centers). Nevertheless, this does not mean that SCs cannot outline specific

strategies, rapidly implement actions to respond to climate change, and learn from the resulting disruptive events. Since networked and hub-and-spoke SCs tend to present a more collaborative relationship among players (Wang et al., 2018; Liu et al., 2022), it is expected that these SCs can better share information on strategic initiatives and more effectively react than linear SCs, where relationships are often less synergistic, and information flows in a more sequenced and less agile manner (Hazen et al., 2021). Due to these facts, although none of the SCs may be highly ready to anticipate, respond, and learn from all types of natural hazards, networked and hub-and-spoke SCs present a moderate readiness, and linear SCs are lowly ready to address these RE potentials.

6. Research propositions and future opportunities

Our reflection led to the formulation of research propositions (RPs) that may be further investigated, expanding, testing, and validating knowledge, especially when the perceived SCs' readiness levels are either moderate or low.

6.1. Monitoring of the potential for disruptions stemming from megatrends

According to our readiness analysis in Table 2, this seems to be the RE potential with the highest readiness across all megatrends and SC structures. Three out of the seven megatrends may present challenging conditions for SCs to know what is critical or can be a threat in the short term (i.e., low or moderate readiness); they are: demographics, geopolitical tension, and natural resources depletion. In all these megatrends, SCs structure appear to have little influence since their readiness level is similar, except for monitoring of natural resources depletion in networked SCs, which was deemed highly ready. This suggests systemic drawbacks in SCs' monitoring ability, especially when considering these three megatrends. Despite the existence of works associating these megatrends and SC management (e.g., Sarkis, 2020; Betcheva et al., 2021; Bednarski et al., 2024), it seems that the specific ability to identify threats and critical issues derived from these megatrends is still poorly addressed. This raises an opportunity for future studies, being summarized by the following RPs:

RP_{1a}. To investigate how SCs, regardless of their structure, can better monitor the potential for disruptions caused by changing demographics and geopolitical tension.

RP_{1b}. To investigate how linear and hub-and-spoke SCs can better monitor the potential for disruptions caused by natural resources depletion.

6.2. Anticipation of disruptions stemming from megatrends

SCs designed to expect disruptions should be able to anticipate threats and opportunities, developing coping strategies (Righi et al., 2015; Tortorella et al., 2022c). Our analysis suggests that SCs might be fairly-well prepared to anticipate disruptions from changing consumer habits, as the development of countermeasures for different demand scenarios is a common practice in marketing strategies (Curry et al., 2006; Canetta et al., 2013). However, as demonstrated by the COVID-19 pandemic, this anticipation capacity is not always effective. Some SCs (e.g., cutlery and domestic equipment) had to scale up their capacity at short-term. As demand for these products has returned to the pre-pandemic levels, some companies were left with idle capacity (Narayanamurthy and Tortorella, 2021). Nevertheless, this high readiness was not observed for other megatrends, such as digital transformation, changing demographics, and climate change. Particularly, linear SCs may struggle with anticipating disruptions from all other six megatrends mainly due to their more rigid structure and hierarchical information and material flows (Hazen et al., 2021), which undermine the systemic implementation of actions to deal with potential threats throughout the entire SC. The anticipation readiness of networked and hub-and-spoke SCs varies across the remaining megatrends. On one hand, we argued that hub-and-spoke SCs may be highly prepared to anticipate disruptions from urbanization due to greater pervasiveness and more agile last-mile delivery, typical of this SC structure. On the other hand, networked SCs may benefit of its complex, multi-tier structure to develop many supply alternatives (Wang et al., 2018), being able to anticipate disruptions caused by natural resources depletion, for instance. Given these arguments, we formulate the following RPs:

RP_{2a}. To investigate how linear SCs can better anticipate disruptions caused by urbanization, digital transformation, changing demographics, geopolitical tension, natural resources depletion, and climate change.

RP_{2b}. To investigate how networked SCs can better anticipate disruptions caused by urbanization, digital transformation, changing demographics, and climate change.

RP_{2c}. To investigate how hub-and-spoke SCs can better anticipate disruptions caused by digital transformation, changing demographics, natural resources depletion, and climate change.

6.3. Responding to disruptions stemming from megatrends

The ability to quickly respond to disruptions is perhaps the most tangible and easily observed RE potential, hence, being quite explored in both SC management research and practice (Parker and Ameen, 2018; Hughes et al., 2023). Despite that, we posed that SCs, regardless of their structure, may present a lower readiness to respond to disruptions originated from digital transformation and climate change. These megatrends often generate sudden impacts (e.g., new technology-driven business models, global internet outages like in July 2024, cyberattacks on critical infrastructures, floods, and bushfires), making it more difficult to react in a short space of time. Furthermore, the set of responses prepared for these megatrends may be more limited (Er Kara et al., 2021; Wirtz et al., 2022), which hinders their ability to address irregular disruptions. In terms of SC structure, the responding potential of linear SCs might be underdeveloped when compared to networked and hub-and-spoke SCs. Due to the existence of parallel flows of information and communication, which tend to create a certain level of redundancy and slack (Righi et al., 2015), networked and hub-and-spoke SCs may respond faster to disruptions, particularly from changing consumer habits and geopolitical tension. However, such an increased SC complexity also implies dealing with a greater number of organizations with distinct organizational cultures. This compounds the challenges associated with an aging workforce (changing demographics), as the effective management of a multigenerational workplace relies on the prevailing organizational values and beliefs (Benson and Brown, 2011; Tortorella et al., 2019). Therefore, we understand more research is necessary to increase SCs readiness regarding their responding ability to specific megatrends, as follows:

RP_{3a}. To investigate how linear SCs can better respond to disruptions caused by changing consumer habits, urbanization, digital transformation, changing demographics, geopolitical tension, natural resources depletion, and climate change.

RP_{3b}. To investigate how networked SCs can better respond to disruptions caused by urbanization, digital transformation, changing demographics, and climate change.

RP_{3c}. To investigate how hub-and-spoke SCs can better respond to disruptions caused by digital transformation, changing demographics, natural resources depletion, and climate change.

6.4. Learning from (successfully and unsuccessfully) coping with disruptions stemming from megatrends

Learning is what enables SCs to systematically improve and become more competitive (Chen et al., 2023), especially when facing disruptive events. Although literature on learning in SCs has been relatively prolific (e.g., Bessant et al., 2003; Gong et al., 2018; Yang et al., 2019), this is apparently an issue for coping with most megatrends. SCs seem to be

Table 3
– Consolidation of research opportunities.

RE potential	SC structure	Changing consumer habits	Urbanization	Digital transformation	Changing demographics	Geopolitical tension	Natural resources depletion	Climate change
Monitoring	Linear SCs				*Gap*	*Gap*	*Gap*	
	Networked SCs				*Gap*	*Gap*		
	Hub-and-spoke SCs				*Gap*	*Gap*	*Gap*	
Anticipation	Linear SCs		*Gap*	*Gap*	*Gap*	*Gap*	*Gap*	*Gap*
	Networked SCs		*Gap*	*Gap*	*Gap*			*Gap*
	Hub-and-spoke SCs			*Gap*	*Gap*		*Gap*	*Gap*
Responding	Linear SCs	*Gap*	*Gap*	*Gap*	*Gap*	*Gap*	*Gap*	*Gap*
	Networked SCs		*Gap*	*Gap*	*Gap*			*Gap*
	Hub-and-spoke SCs			*Gap*	*Gap*		*Gap*	*Gap*
Learning	Linear SCs	*Gap*	*Gap*		*Gap*	*Gap*	*Gap*	*Gap*
	Networked SCs		*Gap*		*Gap*			*Gap*
	Hub-and-spoke SCs				*Gap*		*Gap*	*Gap*

poorly prepared to learn from failures and successes originating from changing demographics and climate change (see Table 2), which is intrinsically related to their lower readiness to respond to them. According to Scholten et al. (2019), learning that occurs during the response phase is often unintentional, resulting from the need to identify and develop a solution to allow SCs to remain operating. In other words, if SCs are poorly able to respond to a specific megatrend, they are prone to present learning difficulties from it as well (Christopher and Peck, 2004). Therefore, the rationale used to determine the readiness levels for SCs' learning ability was similar to responding, regardless of the megatrend and SC structure. The only exception, however, was digital transformation. Although our analysis suggested SCs are moderately ready to respond to the disruptions caused by this megatrend, we suggest that they are highly prepared to learn from it. One of the reasons is associated with the inherent nature of digital transformation. As digital technologies are incorporated into SCs and disturb the existing ways-of-working (CSIRO - Commonwealth Scientific and Industrial Research Organisation, 2016), they may also generate new possibilities for learning through more extensive access to and rapid processing of data (Prashar et al., 2023; Rana and Daultani, 2023). Regardless of their structure, SCs may be well prepared to learn from disruptions caused by digital transformation due to the support of new digital technologies, such as big data, cloud computing, and artificial intelligence. To examine and test our arguments, we raise the following RPs for future studies:

RP_{4a}. To investigate how linear SCs can better learn from disruptions caused by changing consumer habits, urbanization, changing demographics, geopolitical tension, natural resources depletion, and climate change.

RP_{4b}. To investigate how networked SCs can better learn from disruptions caused by urbanization, changing demographics, and climate change.

RP_{4c}. To investigate how hub-and-spoke SCs can better learn from disruptions caused by changing demographics, natural resources depletion, and climate change.

6.5. Final remarks

In summary, the development of SC resilience to cope with and recover from disruptions caused by the aforementioned megatrends is a research topic of both theoretical and practical importance. When considering the different types of SC structure, it becomes clear that existing studies on this topic have not yet covered sufficiently the development of all four RE potentials. SC management literature must expand its scope and breadth to provide a meaningful contribution in the years ahead, as well as deepen the analysis of SC resilience in the face of specific megatrends that seem to be less frequently approached.

It is worth emphasizing that all research propositions, consolidated in Table 3, are hypotheses to be thoroughly investigated based on empirical data in future studies. Although our research propositions were intentionally formulated to consider each RE potential separately facilitating comprehension and properly differentiating the research opportunities, SCs are more likely to thrive when all four potentials are systematically approached. Thus, in practical terms, SCs require the proper development of all potentials (or a set of them), so that they can effectively cope with megatrends' disruptions. Furthermore, the sheer impacts of the megatrends affect not only SCs but societies as a whole. Therefore, SC resilience must be regarded as inseparable from societal resilience, which is defined as the ability of societies to cope with expected and unexpected events that pose major threats to human survivability and the functioning of critical infrastructures (Haavik, 2020). These infrastructures (e.g., healthcare, energy, water, and transport) are systems upon whose reliability, and by implication safety, the functioning of society depends (Almklov et al., 2018). Finally, it is important to acknowledge potential correlations and overlaps between these megatrends, which we did not discuss. The high level of complexity of these megatrends makes subsequent analysis somewhat difficult, resulting in speculative scenarios that may not be fully supported. However, we understand that this interrelationship may aggravate some of the implications for SCs, raising additional insights to both theory and practice. Therefore, we argue that this phenomenon deserves further study and a continuous discussion from a global perspective.

CRediT authorship contribution statement

Guilherme Luz Tortorella: Writing – original draft. **Tarcisio Abreu Saurin:** Visualization, Validation. **Moacir Godinho Filho:** Conceptualization. **Rafaela Alfalla-Luque:** Writing – review & editing. **Andrea Trianni:** Supervision.

Data availability

No data was used for the research described in the article.

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