The role of technology in developing resilient supply chains: a systematic literature review during the COVID-19 pandemic and the disruptions of economic sanctions

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Abstract

Purpose – This study aims to investigate the role of technology in enhancing the resilience of humanitarian and commercial supply chains during disruptions such as the COVID-19 pandemic and economic sanctions.

Design/methodology/approach – A five-step review process for conducting a systematic literature review was adopted to frame future technological interests that depict the role of technology.

Findings – This study identified key technological inventions, such as Industry 4.0 technologies, that help supply chains recover and adapt to crises. The study findings show that while technology offers significant benefits in mitigating disruptions, a gap remains between technological advancements and practical performance, particularly in humanitarian contexts. Humanitarian supply chains require technology that provides quality information sharing and collaborative decision-making capabilities for reactive approaches. Most literature prioritises large and complex data processing and transactions, cybersecurity, hybridised systems, visibility, transparency, interconnection, responsiveness and collaborative technological features that lead to a resilient supply chain and the ability to respond to future crises.

Research limitations/implications – This study explores the role of technology in building resilient supply chain systems during disruptions, using a time-bound approach for efficient research and comprehensive literature analysis.

Practical implications – Understanding the role of technologies in logistics and supply chain activities helps evaluate and select various technologies and technological features to overcome the impact of disruptive events or shocks on supply chains.

Social implications – Shaping, expanding and forecasting the technological requirements for supply chain systems provides the conceptual foundation for developing resilient supply chains.

Originality/value – The new insights from this study demonstrate how the technology was used across industry sectors to overcome the pandemic's and Russian economic sanctions' impact on supply chains.

Keywords COVID-19 pandemic, Technology, Digitalisation, I4.0, Disruptions, Supply chain resilience

Paper type Literature review

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1. Introduction

Digitalisation of supply chains (SCs) (Flechsig *et al.*, 2022) gained considerable attention from global leaders to large organisations during the COVID-19 pandemic (Knight *et al.*, 2022; Zahoor *et al.*, 2022). The trade restrictions (Matthews *et al.*, 2022) to protect against virus spread and the conflict between Russia and Ukraine led to a shortage of key commodities (Curran *et al.*, 2021) and SC disruption (Pereira *et al.*, 2022), raising the need for resilient commercial and humanitarian SCs (Birkel *et al.*, 2023; Thompson and Anderson, 2021). The use of technology played a major role in protecting the spread of the virus and sharing COVID-19 information.

Technology offers the opportunity to bring a new shift (Srai and Lorentz, 2019; Van Hoek, 2021) in the SCs, replacing the current physical logistics and SC system with a new and/or hybrid system, to develop resilience in the SCs. The use of industry 4.0 technologies (I4.0T) has shown promising results in SC performances (Balakrishnan and Usha, 2021; Dongfang *et al.*, 2022; Eslami *et al.*, 2024). Most of the existing literature on the related COVID-19 pandemic focuses either on the impact of the pandemic on SCs (Ardolino *et al.*, 2022; Min, 2023; Patrucco and Kähkönen, 2021) or the digitalisation of SC processes (Vaidya *et al.*, 2018). However, the specific role of technology in building resilient supply chains (RSCs) (Piyathanavong *et al.*, 2024) and mitigating disruptive scenarios remains controversial and uncertain. This controversy and uncertainty are regrettable given the importance of the issue, which has both practical and theoretical implications. It is assumed that minimising SC disruptions (Ivanov and Dolgui, 2021) benefits economic, environmental and social values. Disruptions are inherent features of SC systems due to their complexity, interconnectedness and vulnerability to external factors such as geopolitical sanctions, pandemics and disasters. Technology is seen as a promising means to mitigate those challenges during disruption. For instance, the introduction of digital coins using blockchain technology (BCT) (Choi *et al.*, 2022) to overcome currency freezing during sanction, and the design of personal protective equipment for medical tools using additive manufacturing.

I4.0T play a key role in enhancing the efficiency and resilience of commercial and humanitarian SCs, but their implementation is not without challenges. The limitations can challenge the value of technology in addressing SC disruptions. These drawbacks pose critical challenges when designing and implementing technology-driven solutions. One of the primary limitations in implementing advanced technology is its high investment cost, particularly in the humanitarian SC. The cost of technologies such as blockchain, drones or automated SC systems is difficult, especially for developing economies (Gunasekaran *et al.*, 2024). Integrating technologies is also a critical challenge as it involves diverse systems across the SC. This problem is severe particularly in humanitarian logistics as many stakeholders from non-governmental organizations, government and private stakeholders and donors are involved which may be difficult due to lack of standardisation and interoperability. Such a lack of integration among systems of different stakeholders can result in delays and inefficiencies, especially during emergencies when time-sensitive responses are critical (Gorkhali, 2022).

The application of technologies relies on the availability of accurate and reliable data. However, data availability and reliability are often major issues in disaster-stricken regions, which can lead to poor decision-making and erode the effectiveness of technology (Liu *et al.*, 2022a, 2022b). The growing reliance on technology for managing humanitarian SCs introduces emerging vulnerabilities related to cybersecurity risks, such as data breaches, hacking or cyberattacks, which can severely disrupt humanitarian operations and delay aid delivery (Kalla *et al.*, 2020). Skill gaps and human resources also constrain the use of technology in managing SC disruptions. These constraints can hamper the use and implementation of technologies in humanitarian SC, particularly in crises where human resource capacities are already stretched thin (Murtaza *et al.*, 2004; Wankhede and Vinodh, 2023).

Moreover, technology use and implementation of humanitarian SCs, such as autonomous systems: drones or robots, raise ethical concerns regarding the safety of vulnerable populations and the potential for technology to escalate inequalities. The displacement of the human workforce by technologies can have social implications, particularly in high joblessness countries (Wang *et al.*, 2021a). Furthermore, overreliance on technology can result in a situation where human intuition, experience and flexibility are underestimated. This feature has a strong effect particularly in the humanitarian SC as it requires adapting to rapidly changing circumstances (Chen *et al.*, 2019). In addition, the issue of scaling up is a challenge in implementing technology in SCs advanced technologies can work well on a small scale but face difficulties when implemented in large-scale humanitarian SCs with complex emergencies (Kovács and Spens, 2011).

This paper, therefore, fills this gap in the literature and addresses the controversy and uncertainty by focusing on four primary objectives.

Firstly, the paper intends to highlight the need for RSC systems. The current SC systems were unable to show robustness against SC disruptions. Longer lead times, greater demand variability and higher risks of SC disruptions are observed as a result of the COVID-19 pandemic (Fisher Ke *et al.*, 2022; Patrucco and Kähkönen, 2021). The disruptions of SCs (Bals *et al.*, 2019; Glas *et al.*, 2021) due to business and transport route restrictions resulted in rerouting, supply uncertainty (Moretto and Caniato, 2021), noticeable inflation records (deLisle, 2022; Steffen and Patt, 2022), financial (Yousaf *et al.*, 2022) and transport (Chowdhury *et al.*, 2021) disruptions, excessive logistics costs and missed delivery deadlines (Estrada and Koutronas, 2022) making the current SC system incompetent. Therefore, this study aims to demonstrate the gap between the current SC system and how technology can capacitate the SCM to become resilient to poor circumstances. Secondly, it attempts to demonstrate the importance of a paradigm shift. The paradigm shift could involve replacing the current SC systems with new technological features or hybridised systems to make the SC system more resilient. Thirdly, the paper strives to capitalise on the role of technology in mitigating disruptive scenarios such as COVID-19. Rapid technological development affects the current SC systems by providing a tool to respond to any challenges and competitions. This study identifies five major areas of SC characteristics that are important to overcome disruptions. The final purpose of this study is to investigate promising technologies and technological features that are important in building RSC systems by gaining deep and comprehensive insights into previous research on the role of all technologies in the SC. At the same time, some technical challenges have been identified that require improvement for the proper implementation of technologies, such as privacy and security requirements (Kalla *et al.*, 2020), unreliable outcomes (Tiwari *et al.*, 2024), poor integration capability to the existing devices, scalability, ineffective technology utilisation (Liu *et al.*, 2022a; Rajaguru and Matanda, 2019) and human–machine reconciliation (Choi *et al.*, 2022). However, the effectiveness of technology in shifting the SC paradigms depends on the level of implementation, technical development and the dominance of a particular technology in offering the necessary technological features for most sectors.

From a practical standpoint, this work demonstrates the role of technology in enhancing supply chain resilience (SCR) during and beyond disruptions, as well as the need for a paradigm shift. We encourage organisations to adopt technologies that enhance their SCs, thus improving their ability to resist shocks and adapt to unforeseen events. In this regard, this study seeks to answer the following research question:

RQ1. What has been the role of technology in managing SCs amid the COVID-19 pandemic and Russian economic sanctions?

From a theoretical perspective, this work updates SC technological feature requirements to address current and future challenges and anticipate disruptive technological breakthroughs that could alter SC paradigms by using trendy features to overcome events or shocks. Hence, this work attempts to answer the following question:

RQ2. What technological features are suggested for developing RSCs?

Thus, the paper reviews the role of technology in reducing disruptions and developing RSCs for commercial and humanitarian, focusing on current trends and future technological requirements. We have contributed to research by analysing and reporting on how technology can develop SCR. Our framework shows the industry's experience and potential during COVID-19. This paper is structured into seven sections:

Section 1 provides an overview of the research and defines the aim and objectives of the present study; Section 2 provides an overview of SCR; Section 3 provides the research approach followed in conducting the study; Section 4 presents the main findings and analysis; Section 5 presents research needs and discussion; Section 6 presents the implications of the study; and finally Section 7 presents the conclusion of the study.

2. Supply chain resilience

The global pandemic (Chowdhury *et al.*, 2021; Das *et al.*, 2022b) and the war between Russia and Ukraine exposed the SC integration vulnerabilities (Acevedo and Lorca-Susino, 2021; Adekoya *et al.*, 2022; deLisle, 2022; Estrada and Koutronas, 2022) and put SCR into question (Curran *et al.*, 2021). Individuals, organisations, companies and countries have been impacted by these disruptions. In this kind of scenario, the role of technology becomes very important in reducing supply shortages such as oil (Adekoya *et al.*, 2022) and raw materials and maintaining transportation prices as low as possible by creating and forecasting necessary SC characteristics, responsibilities and duties, thereby strengthening the crisis management system.

The role of technology is considered essential in creating RSCs, both for commercial and humanitarian SCs. Firms' ability to exploit and explore new ideas helps them overcome disruptions and build SCR using I4.0T (Charles Arthur *et al.*, 2022). The study by Chowdhury *et al.* (2021), on the role of technology in the implementation of resilient strategies, summed up the strategies for minimising the impacts of COVID-19, recovering from the current pandemic and preparing for future pandemics, as three main disruptions of SCR:

1 preparedness;
2 response; and
3 recovery.

Previous studies on the role of technology in implementing resilience strategies suggested only low-tech solutions to the problem, such as health-care SCs, the use of additive manufacturing (AM), mobile service operations, drones and artificial intelligence (AI). However, technologies are available to build RSC with a combination of other resilient attributes or strategies (Magableh, 2021). I4.0T such as blockchain, robotics, Internet of Things (IoT), AI, big data analytics (BDA) and cloud computing (CC) are rarely studied for their role in managing disruption and ensuring resilience (Chowdhury *et al.*, 2021). Most literature (Kumar *et al.*, 2022; Roma and Adriana, 2021) associates the use of AM technology only with specific applications, such as medical and personal protection equipment (PPE). However, this literature revealed the role of AM technology in various roles, particularly during disruption periods, such as remanufacturing and diminishing waste resources by employing just-in-time production. The manufacturing of PPE and health-care equipment for hospitals was achieved through collaborative platforms, with printers and volunteers assisting. However, discovering and classifying proven designs was challenging, as most designs were published online without official testing or certification. The pandemic and geopolitical crises have exposed the vulnerability in the health-care sector underscoring the necessity of developing robust and RSCs that can withstand future challenges. Digital technology (DT) showed its capabilities in improving health-care SCR during disruption periods. The integration of DT significantly changed the health-care sector, enhancing visibility, transparency and stakeholder collaboration (Chen *et al.*, 2019; Tiwari *et al.*, 2024). The implementation of DT for tracking and tracing important medical supplies, such as PPEs, medicines and vaccines, attracted the interest of global health organisations. However, we acknowledge some technical challenges that require improvement for the proper implementation of technologies. The unreliable outcome of BDA and AI tools is due to a lack of end-to-end visibility in the

SC, an overwhelming amount of data that can lead to poor decision-making (Tiwari *et al.*, 2024), poor integration capability to the existing devices and inequality in access to technology that leads to a digital divide and SC integration challenges.

Naz *et al.* (2022) proposed that future technology adoption could reduce the social, economic and environmental impacts of SCs and/or transportation and logistics. The technological progress could also help develop a framework for supplier selection and RSC network design. While designing resilient and robust SCs, it is mandatory to consider technology that overcomes future risks, such as SC network disruptions (Das *et al.*, 2022a; Van Der Vegt *et al.*, 2015), cybersecurity and theft behaviours. Four fundamental design principles were proposed for digitising purchasing and SC management, interconnection, information transparency (Van Hoek, 2020), decentralised decisions and technical assistance (Srai and Lorentz, 2019). The upcoming technology is expected to improve organisational competencies such as openness to a new solution and process optimisation (Bals *et al.*, 2019). Digital twin, data-driven SC risk analytics systems, can aid decision-making in historical analysis, predictive optimisation, simulation of alternative designs, real-time recovery control and learning and disruption pattern recognition, providing a basis for managing disruption risks in SC (Ivanov and Dolgui, 2021).

A significant number of studies demonstrate the potential of DTs to shift the paradigm of the SC system (Srai and Lorentz, 2019). This study highlights how current technology shifts future SC activities by using the relationships between technological progress and SC development. Digitalisation significantly influenced the development of crisis protocols during the COVID-19 pandemic, primarily due to the need for physical distancing measures (Durugbo *et al.*, 2022). All technologies, strategies, techniques and approaches enable firms to close the gap, which helps to develop an RSC system (Magableh, 2021). As firms increase their global footprint and the number of global partners, the demand for DT adoption increases (Matthews *et al.*, 2022). Based on the current industrial experience, compatible, reconfigurable, interconnected and collaborative (Küffner *et al.*, 2022), responsive (Frederico *et al.*, 2023) and consistent technological features are among the upcoming requirements of technological characteristics that lead to an RSC to respond to future crises. It is highlighted that large and complex data processing and transactions, cybersecurity, hybridised systems and improved integration between blockchain, AI, IoT and data analytics features are prioritised by most sectors to meet their objectives and respond to future challenges. The use of technology in SCs is crucial for fostering trust among stakeholders (Haddud *et al.*, 2017). However, ineffective technology utilisation can lead to miscommunication, data inaccuracies and a lack of transparency, causing misunderstandings, conflicts and disruptions (Liu *et al.*, 2022a; Rajaguru and Matanda, 2019). A computer security update in July 2024 disrupted the aviation industry and other businesses. Airlines like Delta, American and United issued ground stops and manually checked in passengers. Such disruptions in the SC highlight the importance of ensuring the safe and effective utilisation of technologies. Establishing clear protocols and ensuring data integrity is essential for mitigating risks associated with technological failures (Abou Kamar *et al.*, 2023).

I5.0 technology, which favours human–machine (Choi *et al.*, 2022) and SC stakeholder collaboration, is expected to contribute to developing RSCs and network connectivity. IoT, BCT and digital twins have the potential to provide connectivity between SCs, which helps to develop RSCs. The presence of smart materials in I5.0 technologies plays a major role in performing multiple functionalities and capabilities in a chaotic environment such as the COVID-19 pandemic (Jefroy *et al.*, 2022). In their work, Choi *et al.* (2022) highlighted the potential pitfalls of human–machine reconciliation for achieving coexistence between machines and humans in the context of sustainable social welfare. However, users should make better decisions about the role of technology. Humans create technology to perform particular objectives; however, one can use it for unethical activities. Therefore, the potential of those technologies lies not in the technologies themselves, but in how they are leveraged.

3. Research methodology

This review adopted an established five-step (Figure 1) process for conducting a systematic literature review (SLR). Denyer and Tranfield (2009) suggest an SLR to pass through research question development, literature selection, article evaluation systems to include or exclude, data analysis and synthesis and reporting findings.

3.1 Developing research questions

An initial extensive explanatory literature review in the area of SC and technology during the COVID-19 pandemic and the ongoing Russia–Ukraine war (Ardolino *et al.*, 2022; Pörtner *et al.*, 2022), led to the development of *RQ1* and *RQ2* to systematically review the literature.

3.2 Literature selection strategy

This literature review aims to develop a comprehensive understanding of a research problem by minimising bias using four search criteria:

1 timeframe;
2 database;
3 journal selection; and
4 keywords.

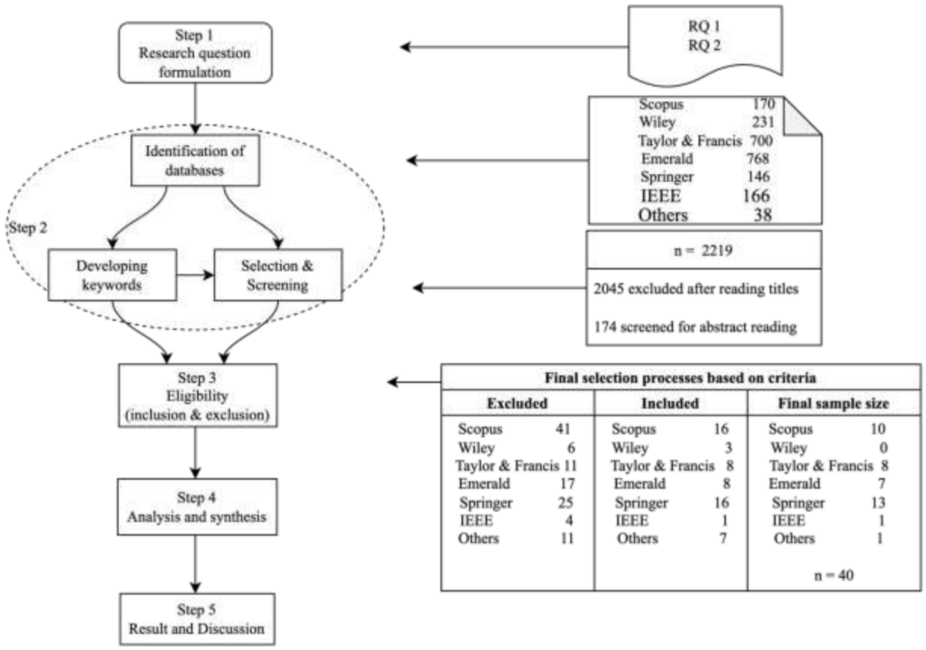
The first known COVID-19 outbreak was reported in December 2019 (Cordeiro *et al.*, 2022). However, without developing the capability to adapt and customise the pandemic consequences, the conflict between Russia and Ukraine, which started in February 2022, led to unprecedented economic and social sanctions against Russia (Nguyen and Do, 2021; Tosun and Eshraghi, 2022), as well as the SC crisis. For this reason, articles published between January 2020 and September 2022 were explored and considered.

To identify scholarly and peer-reviewed journal articles related to SCM and technological progress Scopus, Taylor & Francis, Wiley, Springer, Emerald and IEEE databases were explored.

To ensure the standard of our systematic review, we strictly considered peer-reviewed journals in line with our research questions.

To find the relevant articles, we used preliminary surveys and iteration methods on internet databases to select 19 keywords

Figure 1 Systematic literature review process



Source(s): Authors' own work

from the technologies and SCR-related literature. Literature searching is performed using the following key terms "supply chain" AND "disruption" OR "COVID-19 pandemic" OR "Russia-Ukraine war" AND "technology" OR "industry 4.0" OR "digitalisation" OR "artificial intelligence" OR "blockchain" OR "additive manufacturing" OR "big data analytics" OR "cloud computing" OR "internet of people" OR "internet of things" OR "augmented reality" OR "automation" OR "robotics" AND "resilience" OR "supply chain resilience" on titles based on Boolean logic. In total, 2,219 English-language articles were found using the more specific search criteria. The domain of journal articles was considered within the scope of procurement, logistics, operations, SC management, purchasing, transport, manufacturing, industrial marketing, information systems, business, production economics, technology and integrated SC.

3.3 Inclusion and exclusion criteria

The screening and shortlisting mechanism was reading the title of the articles based on current technologies and future forecast contributions (Rad *et al.*, 2022; Vaidya *et al.*, 2018). Following the scope of this review, publication coverage related to the title and after finding no or very few keywords in the article using a manual search, 2,045 journal articles were dropped. After reviewing the abstract of 174 articles, 115 articles are excluded from further investigations, due to a lack of detailed information about technological contribution during the pandemic. The remaining 59 articles were considered for further reading and a total of 40 articles were used for this SLR.

To ensure the validity of the work and avoid the rejection of a good sample, manual keyword searching was performed on each excluded article.

3.4 Literature analysis and synthesis

The sample articles were synthesised and analysed to gain new insights and knowledge. Braun and Clarke's (2006) inductive theme research analysis methodologies were applied to analyse and summarise the key role of technologies. Technology's contribution to SCs during the COVID-19 pandemic and Russian economic sanctions was classified, organised and systematised to examine the literature's contribution (Table 2).

After reading Table 2 and re-reading the literature to become acquainted with the main concepts, iterations such as collecting similar technological roles and technologies together to develop initial codes were performed. It is then organised and systematised to generate themes. This includes defining codes and analysing the themes. The relationships between the data items and codes, as well as those between the themes and data sets, were examined. From the data extraction, the final themes were defined, named, arranged and reported. The following major technological roles (themes) are formulated from Table 2: information gathering, analysis and sharing; visibility and transparency; collaboration and integration; automation and efficiency; and analytical and innovative capability. Finally, the analysis of these data was used to reveal or frame the current role of technology and upcoming SC requirements.

4. Analysis and findings

Our study highlights the potential of technology in enhancing SCR during disruptions, but also highlights a gap between technological advancements and performance, emphasising resistance and recovery in humanitarian SCs. We have contributed to the research community by identifying, analysing, synthesising, interpreting and reporting the fragmented literature on the role of different technologies in developing

SCR. We have developed, a comprehensive framework (subsection 4.3) that reveals the industry's experience and the potential of technology during the COVID-19 disruption.

4.1 Descriptive analysis of journal contributions

Table 1 presents academic journal guide rankings and paper numbers for 2022 journals retrieved from the Scimago Journal and Country Rank databases. The *International Journal of Production Research*, *Operation Management Research* and the *International Journal of Operations and Production Management* have the highest technological contribution coverage.

4.2 Identification and evaluation of technological role during the COVID-19 pandemic

Technology is crucial in logistics and SC management during disruptions like geopolitical conflicts and pandemics. It assesses risks (Ivanov and Dolgui, 2021; Park and Singh, 2023; Sharma *et al.*, 2022; Van Der Vegt *et al.*, 2015), enhances visibility (Ivanov, 2024; Tiwari *et al.*, 2024), optimises routes (Ershadi and Shemirani, 2022; Li *et al.*, 2022a; Oksuz and Satoglu, 2023) and provides predictive analytics for proactive (Qrunfleh *et al.*, 2023) decision-making. The application of technology in such situations varies based on specific challenges and requirements and depends on the strategies and technologies adopted by logistics professionals.

Table 2 presents the technological role during disruptions, including the journal's published articles, context and technologies used. The table is used for designing trendy technological features (Figure 3), dominant technologies (Figure 4) and technological frameworks.

4.3 Technological framework to develop supply chain resilience

Digitising the SC process, which involves planning, implementing, controlling, marketing, distributing, financing and storing goods and materials, provides information sharing, transparency, automation, flexibility and collaboration capabilities that enable resilient and sustainable SC systems capable of responding to and recovering from disruptions. For instance, using unmanned aerial vehicles (UAVs) in humanitarian SCs aids network connectivity, facilitates data collection and enables the delivery of medical supplies, food and equipment to inaccessible areas or areas with damaged infrastructure, thereby improving response times (Masroor *et al.*, 2021). In various and large-scale agriculture SCs, this UAV technology can also be effectively used for crop spraying, monitoring, irrigation and fertilisation tasks. However, the effectiveness of technology in shifting the SC paradigms depends on the level of implementation, technical development and the dominance of a particular technology to offer the necessary technological features for most sectors. The BCT provides COVID-19 patient information sharing to handle immigration and emigration processes, building a more RSC by establishing an immutable recording of data logs, supporting audibility, provenance and transparency and food distribution (Kalla *et al.*, 2020; L'Hermitte and Nair, 2021). To fully implement BCT and get its benefits, a few obstacles, such as privacy and security requirements, legal disputes, scalability and resource utilisation efficiencies, must be overcome (Kalla *et al.*, 2020).

Following a comprehensive review, we have framed five critical technological applications (Figure 2) that are essential in developing the RSC system based on the experience of the COVID-19 pandemic disruption. This framework shows the role and features of technology in overcoming SC challenges during disruptions. The framework systematically answers the research questions. The selected articles are analysed using the main frameworks discussed in the following subsections.

4.3.1 Information gathering, analysing and sharing

The adoption of diverse DTs to manage the overall SCs (Akbari and Hopkins, 2022) helps to develop resilience, which is the ability of a firm to sense, adapt to and quickly respond to the changes, in SCs (Li *et al.*, 2022b). In the literature, it is explored how DTs assist businesses in creating a coordinated SC through information sharing and collaborative decision-making, which may improve the four key elements of resilience, namely, flexibility, transparency, visibility and agility. Agility

Table 1 Journal contributions on the role of technology during disruptions

Journals	Journals impact factor (SJR 2022)	No. of the article (%)
Journal of Purchasing and Supply Management	2.09 (Q1)	2 (5)
Operations Management Research	0.79 (Q2)	9 (22.5)
Industrial Marketing Management	2.66 (Q1)	3 (7.5)
Annals of Operations Research	1.05 (Q1)	3 (7.5)
International Journal of Operations and Production Management	2.62 (Q1)	5 (12.5)
International Journal of Production Economics	3.03 (Q1)	2 (5)
International Journal of Supply Chain Management	–	1 (2.5)
International Journal of Production Research	2.98 (Q1)	8 (20)
Transportation Research Part E	3.01 (Q1)	1 (2.5)
Technological Forecasting and Social Change	2.64 (Q1)	1 (2.5)
Computers and Industrial Engineering	1.76 (Q1)	1 (2.5)
International Journal of Logistics Management	1.47 (Q1)	2 (5)
Information Systems Frontiers	1.42 (Q1)	1 (2.5)
IEEE Transactions on Engineering Management	1 (Q1)	1 (2.5)
Total		*40*

Source(s): Authors' own work

Table 2 Technological role during the COVID-19 pandemic

Article no.	Journals	Literature	Method	Author(s)	Context	Technology used	Description	The role of technology during disruptions
1	*Journal of Purchasing and Supply Management*	Theoretical	Conceptual	Moretto and Caniato (2021)	SC finance (SCF)	Electronic invoicing	Electronic payment to implement SCF	Modernise and dynamic pricing system
						AI	A promising technology for SCF	SCF efficacy Automating activities Data sharing and analysis
2	*Journal of Purchasing and Supply Management*	Empirical	Mixed	Van Hoek (2021)	Purchasing and SCM	RFID Blockchain	Technologies that are capable to store and exchange digital contents	Information sharing Demand visibility Transparency of inventory
3	*Operations Management Research*	Empirical	Quantitative	Sharma *et al.* (2022)	Food SC	Blockchain	Evaluation of BCT-enabled food SCs resilient strategies that mitigate the effect of disruption	Traceability and flexibility Demand and supply shock control Real-time information sharing and monitoring
4	*Operations Management Research*	SLR	SLR	Hald and Coslugeanu (2022)	COVID-19 pandemic implications on the global SC	Digitalisation/technology (generic)	How technology enhances resilience	Flexibility Visibility Collaboration Agility
5	*Operations Management Research*	Empirical	Quantitative	Das *et al.* (2022a)	SCR	Process automation and AI	Considered as the critical factors for resilient SC to combat COVID-19	Assessing situations and acting Manage information asymmetry and an uncertain environment Connectivity Transparency Accuracy
6	*Operations Management Research*	Empirical	Quantitative	Chatterjee and Chaudhuri (2022)	SC sustainability	Technology (generic)	How technological capability of a firm impact SC sustainability to address any turbulent environment?	Innovation capability
7	*Operations Management Research*	SLR	SLR	Naz *et al.* (2022)	Resilience in SC operations	AI	Investigating AI's significant impact on creating sustainability and resilience	Adaptability and information processing Flexibility
8	*Operations Management Research*	Theoretical	Qualitative	Dongfang *et al.* (2022)	The part of I4.0 technology and circular economy (CE) in building resilient SC	Industry 4.0 technologies	The future I4.0 in developing RSC and its role during the pandemic	CE implementation Processing times reduction Integration in the SC Production process flexibility
						Blockchain		Improve shipping time Reducing waste and costs Communication
						IoT		Improved collection, transport and processing of commercial waste
9	*Operations Management Research*	Empirical	Quantitative	Akbari and Hopkins (2022)	The extent of I4.0 adoption and its support to build sustainability in Vietnam	BDA AM	To study the impact of I4.0 technology on Vietnam's SC	Forecasting and recognition of sales and market Product customisation. Customer value propositions Reducing stock and waste across the SC Reducing transportation and storage cost Responsiveness
						Advanced robotics Autonomous vehicles Drones AI		Delivery and manufacturing automation Performances and reduced inefficiency Delivery and cost reduction Improved performances and reduced inefficiency Fraud and risk management Inventory placement
						IoT BCT		SC efficiency, real-time tracking and traceability Record accuracy, SC transparency and contract management
						AR		Communication and visualization

(*continued*)

Table 2

Article no.	Journals	Literature	Method	Author(s)	Context	Technology used	Description	The role of technology during disruptions
10	*Operations Management Research*	Empirical	Qualitative	Piyathanavong *et al.* (2024)	Sustainable SC (SSC)	Industry 4.0 technologies	How I4.0 and CE contribute to SSC development	Process connection Product customisation Collaboration Encourage and support CE implementation Minimise costs
11	*Operations Management Research*	Empirical	Quantitative	Liu *et al.* (2022b)	The importance of digital technology in CE	Digital technologies (generic)	The use of technology on organisational performance	Organisational performances to achieve CE plans
12	*Industrial Marketing Management*	Empirical	Qualitative	Matthews *et al.* (2022)	Understanding the new normal in industrial firms	Emerging technologies such as omni-channels, digital e-commerce and/or hybrid system	How industrial firms used the adaptive systems to overcome the disruption. Leveraging technology in new ways	New communications. Virtual interactions
13	*Industrial Marketing Management*	Empirical	Qualitative	Zahoor *et al.* (2022)	The role of technology for dynamic capability and agility in B2B high-tech small and medium enterprises	Blockchain IoT AI e-Commerce omnichannel	Technology utilisation is a primary means to overcome the disruption of COVID-19	Online presence and communications Inventory management
14	*Industrial Marketing Management*	Empirical	Mixed	Dubey *et al.* (2021a)	The effect of AI on SC operational and financial performances under different mediating factors	AI	AI-driven SC analytics capability as dynamic capabilities	Analytical capability Collaboration Interorganisational learning Accessing technology and resources Fostering innovation
15	*Annals of Operations Research*	SLR	SLR	Queiroz *et al.* (2022)	How to use technologies to manage SC	Blockchain AI AM	The role of digitalisation to mitigate the impacts of the COVID-19 pandemic in commercial SC	Visibility Responsiveness Traceability
16	*Annals of Operations Research*	Empirical	Quantitative	Cui *et al.* (2023)	Manufacturing firm resilience during SC disruptions	Generic (collective digital technologies, BDA, CC, IoT)	DTs help firms process information, which determines firm resilience	Information and resource exchange and utilisation Responsiveness Operational efficiency
17	*Annals of Operations Research*	Case study	DEMATEL	Kazancoglu *et al.* (2023)	Sustainability and resilience of SC in an uncertain environment	AI	Based on previous and ongoing COVID-19 challenges, how can emerging technologies be used to build sustainability and resilience?	Decision-making Purchasing planning and traceability Tracking systems Efficiency and effectiveness Reduce planning errors, delivery delays and fluctuations
18	*International Journal of Operations and Production Management*	Theoretical	Event-study	Chen *et al.* (2021)	Digital transformation to enable SC finance	DTs Information integration IT BDA digital platform	Reverse factoring Purchase order finance SCF initiatives SCF solutions	Risk mitigation Integrated SCF
19	*International Journal of Operations and Production Management*	Theoretical	SLR	Barbieri *et al.* (2021)	Digital supply chain governance (buyer and supplier perspectives)	Generic	How the digital transformation is impacting the structure, practices and performance of inter-organisational governance in SCs	Coordination Control
20	*International Journal of Operations and Production Management*	Theoretical	Concept	Sarkis (2020)	Sustainability and resilience in SC	Technological innovations and implications Virtual reality linked cyber physics system technologies	Data-driven actions to respond to the COVID-19 crisis. To manage actions at a distance. I4.0 technologies are enablers of crisis management	Data sharing
21	*International Journal of Operations and Production Management*	Empirical	Mixed	Dennehy *et al.* (2021)	Crisis management (humanitarian SCs)	BDA capabilities	Optimising SCs	Overload, multi-tasking and information processing Responsiveness Decision-making Visibility and transparency in SC

(continued)

Table 2

Article no.	Journals	Literature	Method	Author(s)	Context	Technology used	Description	The role of technology during disruptions
22	*International Journal of Operations and Production Management*	Empirical	Quantitative	Xiong *et al.* (2021)	Mitigation capability of firms with lean and complex SC	BCT	To enhance transparency and traceability	Cut abnormal stock returns Mitigation Contingency
23	*International Journal of Production Economics*	Theoretical	Quantitative	Narayanamurthy and Tortorella (2021)	The moderating role of I4.0 to the relation between COVID-19's work implications on employees' performances	I4.0 (IoT, BDA, CC and machine learning)	Enhance employee and organisational flexibility and performance. Reduce costs, increase speed and quality improvement	Communication and information sharing Support decision-making
24	*International Journal of Production Economics*	Empirical	Quantitative	Ye *et al.* (2022)	DTs capability to mitigate COVID-19 between firms with high and lower levels of DTs	Overall DTs asset deployment of a firm	Based on asset orchestration perspectives, breadth (scope) and depth (scale)	High levels of SC visibility
25	*International Journal of Supply Chain Management*	Theoretical	Case study	Rajesh (2022)	SC and operation optimisation to build resilience and flexibility for disruption scenarios	Blockchain	The decentralised, secured, immutability, traceability and transparency options of BCT promote and nurture several sectors	B2B ordering automation
						AI	The ability of AI to perform large complex data with greater accuracy, speed and agility, makes it preferable to optimise demand forecasting, ordering, inventory and transportation systems during the pandemic	Self-driving truck systems for product delivery and replace drivers
						IoT	The IoT helps to track and authenticate products across the SC process	Communication and collaboration Data generation, storage and sharing capabilities
						E-commerce	Online presence	Online marketing and communications
26	*International Journal of Production Research*	Empirical	Quantitative	Dubey *et al.* (2021b)	How collaborative partnerships built through AI-driven BDA capacity and intergroup leadership improve agility in humanitarian SCs	AI	Shows how information alignment, collaboration and AI-driven BDA capability impact SC agility	Information alignment and sharing Collaboration
27	*International Journal of Production Research*	Empirical	Mixed	Ivanov (2021)	Technology-driven disruption adaptation strategy	Generic	How digital technology is exploited to adapt to the COVID-19 pandemic for viable SCs	Developing SCs viability Order patterns and deviations control (visibility)
28	*International Journal of Production Research*	Empirical	Quantitative	Alexopoulos *et al.* (2022)	A measure for resilience in manufacturing systems	AM (3D printing)	Creating a 3D physical object from digital data	Resilience estimation (in terms of cost)
29	*International Journal of Production Research*	SLR	Quantitative	Nayernia *et al.* (2022)	Implementation of I4.0 from an organisation perspective	I4.0	The impact of the COVID-19 pandemic on I4.0 implementation is within the tension between value creation, protection and contingency approach	Remote working Increasing resilience and optimising resource management Information sharing
30	*International Journal of Production Research*	Theoretical	Design science approach	Kalaiarasan *et al.* (2023)	SC visibility in inbound logistics	RFID Bluetooth technology Long-range technology Ultra-narrowband technology	Evaluation of various technologies for capturing and transmitting data to potentially improve the SC visibility of the firm's inbound logistics. Improving deviation and predictive capability	High connectivity and tracking precision Connectivity and precision tracking Good connectivity and network-dependent tracking capability High connectivity and tracking precision

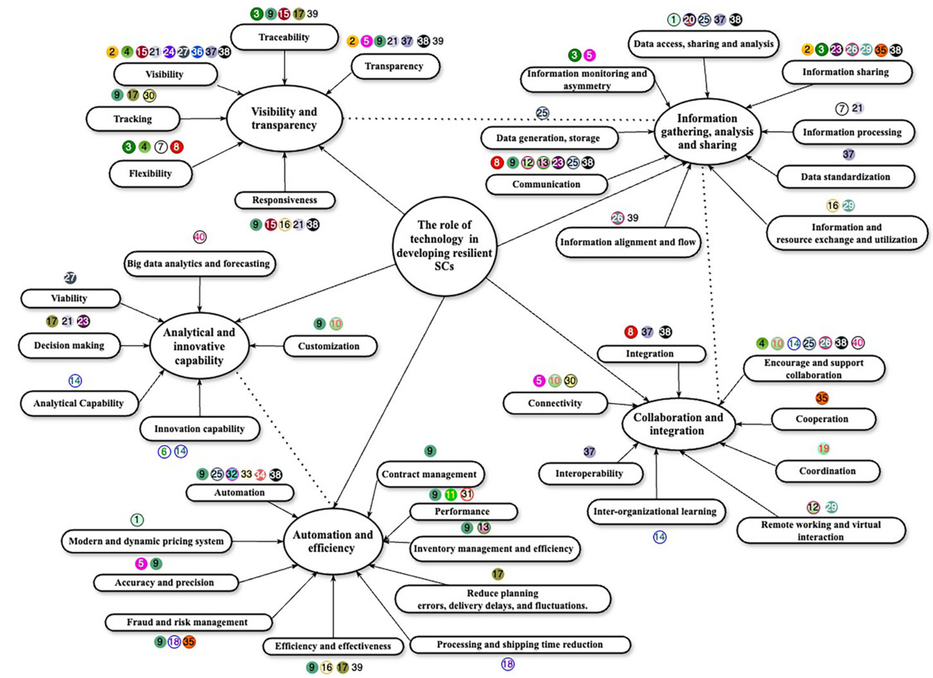
(*continued*)

Table 2

Article no.	Journals	Literature	Method	Author(s)	Context	Technology used	Description	The role of technology during disruptions
31	*International Journal of Production Research*	Empirical	Quantitative	Badakhshan and Ball (2023)	Inventory and cash management in SC	Digital twins	The potential of digital twins to manage inventory and cash throughout the SC during disruption	SC performance A reduction in the cash conversion cycle for upstream members of the SCs
32	*International Journal of Production Research*	Theoretical	Conceptual	Singh *et al.* (2022)	Personal protective equipment (PPE)	AM	Benefits such as creating anatomically matching devices, as per the individual requirements, easy creation of porous fabric structures and fabrication of complex geometrical structures and tortuous channels	Production of PPE
33	*International Journal of Production Research*	Theoretical	Conceptual	Sodhi *et al.* (2023)	PPE	AM system (3D printing)	Research direction on technology as a whole	For rapid production of PPE
34	*Transportation Research Part E*	SLR	SLR	Chowdhury *et al.* (2021)	SC during COVID-19 Pandemic	Generic (AM)	Technological contribution in implementing resilience strategies	PPE and ventilators
35	*Technological Forecasting and Social Change*	Empirical	Mixed	Belhadi *et al.* (2021)	Developing SCR in manufacturing and service	I4.0	The importance of digital technology for SCR's long-term reactive and proactive disruptive response strategy	Risk mitigation strategies Real-time information sharing and cooperation using BDA
36	*Computers and Industrial Engineering*	SLR	SLR	Spieske and Birkel (2021)	SCR in the automotive industry	I4.0	Improving SCR through I4.0	Visibility and velocity
37	*The international Journal of Logistics Management*	SLR	Use case analysis based on CIMO logic	Kayikci *et al.* (2022)	Food SC	BCT	To explore the potential of BCT to support operational excellence in perishable food SC	Data immutability and transparency Visibility Integration Interoperability Asset management Disintermediation and data decentralisation Data standardisation, security and sharing
38	*The international Journal of Logistics Management*	Empirical	Quantitative	Frederico *et al.* (2023)	Impact of I4.0	I4.0 technologies	To investigate the interoperability of disruptive technologies	Self-executed and controlled SC processes Information exchange and communication Data access and analysis Visibility and velocity of SCs SC integration Collaboration Responsiveness Transparency
39	*Information Systems Frontiers*	Theoretical	Case study	Sengupta *et al.* (2022)	Fish SC in a developing country	Blockchain Satellite imagery	How BCT helps to build SC resilience by overcoming fish SC challenges	Product flow information Transparency and traceability No intermediaries Cost and time reduction in the process
40	*IEEE Transactions on Engineering Management*	Theoretical	Concept development	Ivanov (2024)	The use of technology to enhance SC resilience by building and using end-to-end visibility during the COVID-19 pandemic	Early warning system Blockchain and track and trace technologies BDA AI Digital collaborative SC platforms	Investigating the potential and implementation of end-to-end visibility in the management of SC resilience	Detection of potential disruptions Real-time recognition of real disruptions Analysis of disruption Analysis of disruption Collaboration and disruption management

Note(s): B2B = Business-to-business
Source: Authors' own work

Figure 2 Five major areas of technological application during the pandemic



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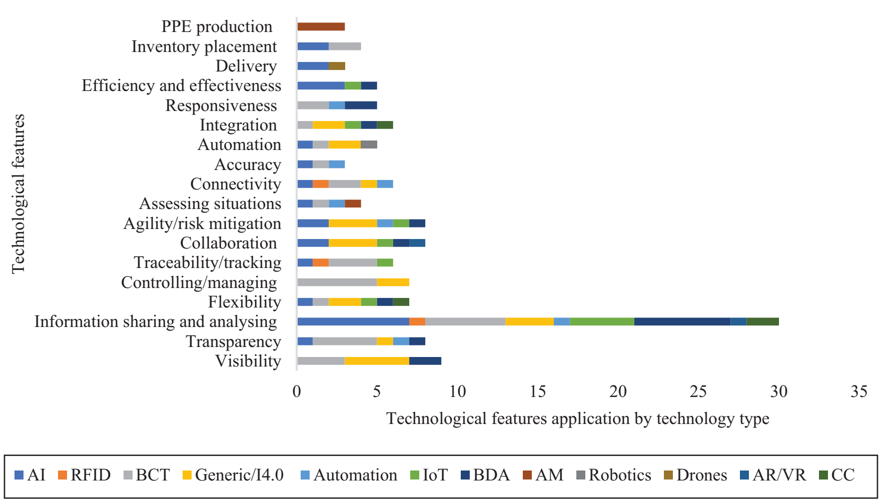
and SC risk management culture can both positively affect resilience (Hald and Coslugeanu, 2022).

During the pandemic, the most prevalent technological features were information and data gathering, processing and sharing; visibility; transparency; collaboration; and tracking (Figure 3). This and other features are investigated as enablers of SCR. The resilient antecedents that benefit from overcoming SC disruption from AI, BCT, BDA and IoT technologies are visibility, transparency, collaboration, traceability and risk mitigation (Figure 3). Chen *et al.* (2019) and Kalaiarasan *et al.* (2023) claimed radio frequency identification to collect data, IoT to manage data, CC to increase visibility, BCT to provide visibility and security, AI to support prediction and visibility and BDA to improve visibility and predictive capability (Ivanov and Dolgui, 2021). While technology offers numerous advantages for enhancing SCR, numerous challenges remain open to further improvements. System failure, cyberattacks and loss of data privacy and security are some of the associated risks of

Figure 3 Trendy technological SC features



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technology (Van Der Vegt *et al.*, 2015). As the SC businesses are interconnected and integrated, the SCR depends on technological performance, and individual organisational capability to overcome disruptions that affect the overall SC network. Furthermore, adopting any of these technologies requires affordability, adaptability and an assessment of capabilities, cost and associated risks. Also, organisations face challenges from first-movers as they implement innovative technological features.

The COVID-19 pandemic affected a firm's visibility, which might be enhanced by the technological capability for data collection, management and analytics and connectivity (Belhadi *et al.*, 2021; Kalaiarasan *et al.*, 2023). I4.0 technology enhances business operations management, resource circularity, product quality and manufacturing flexibility (Fragapane *et al.*, 2022), promoting information sharing and collaboration among stakeholders (Hald and Coslugeanu, 2022; Piyathanavong *et al.*, 2024). However, the increased reliance of the global SC economy on technology raises security concerns at all levels, including small firms and multinationals. Information flows (Chen *et al.*, 2019) across the SC process pose significant risk management challenges for SC partners. Information disruptions to SC processes could result in economic, customer and market losses (Dynes *et al.*, 2007; Skipper and Hanna, 2009).

Compared to commercial SCs, humanitarian SCs require an emerging technology for reactive approaches, such as big data analytical technologies (Dubey *et al.*, 2021b). SC readiness, responsiveness and recovery require quality information sharing using emergent technologies to respond, mitigate disruption and recover from it, which also helps in enhancing resilience in the SC. Our finding indicates that obtaining well-organised and high-quality humanitarian SC data is not straightforward. By implementing technology, humanitarian organisations can gain access to this data. To enhance future preparedness, a robust technological infrastructure is necessary to process and convert humanitarian supply chain data into meaningful information. However, these technological infrastructures are expensive, time-consuming to implement and donor-dependent for humanitarian organisations. DTs improve firm information processing, resilience and flexibility in high-information-complexity environments by integrating supplier, customer and internal processes, enhancing supplier diversity and inclusion (Cui *et al.*, 2023; Xiong *et al.*, 2021).

Our analysis revealed that information gathering, analysis and sharing played a vital role in coordination, collaborative decision-making, connectivity and manufacturing flexibility, which helped to improve the SCRs.

4.3.2 Visibility and transparency

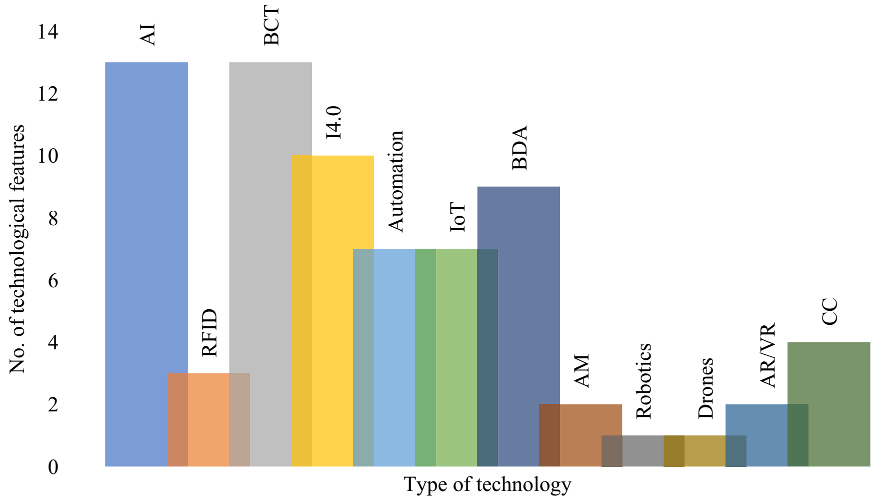
Ensuring visibility and transparency between the downstream and upstream partners can significantly reduce the vulnerability in SCs. Among the I4.0Ts, end-to-end visibility, transparency, flexibility, a shorter SC network structure and tracking of goods across the SCs make the BCT (Figure 4) preferable to improve operational excellence (Dennehy *et al.*, 2021; Sharma *et al.*, 2022; Spieske and Birkel, 2021).

While AM, drones, augmented reality (AR)/virtual reality, CC and robots have demonstrated their importance in developing RSCs, they have shown the fewest technological features to overcome shocks in the SC compared to AI and BCT (Figure 4). However, one or more technologies are anticipated to stand out from the crowd by offering the necessary technological features and having to change SC paradigms. BCT is a decentralised platform that obviates the need for a middleman (Ivanov, 2021) and permits peer-to-peer direct transactions while also validating data. SCR is achieved because the secure, decentralised platform minimises disruptions caused by data inaccuracies or intentionally fraudulent activities. Due to the lesser dangers of hacking, contractual disputes, negotiated privacy, political instability, expensive adherence to governmental norms and regulations and uncertainties related to financial institutions, BCT is preferred (Kayikci *et al.*, 2022). Blockchain helps overcome challenges in humanitarian SC, such as resource waste, poor collaboration, theft behaviours and trust, by providing traceability and transparent information, reducing disruption risks during COVID-19 and fostering trusted approaches (Jellason *et al.*, 2024; Kumar, 2020; Xiong *et al.*, 2021). Moreover, BCT showed improved food product quality, responsiveness, employee tracking and reduced cost of SC transactions (Kayikci *et al.*, 2022; Kumar and Kumar Singh, 2022). Ye *et al.* (2022), discussed the breadth and depth of DTs deployment of firms that might affect a firm's SC visibility, access to high-quality information, agility and ability to adapt to market changes. In their analysis, both breadth and depth of DTs of asset deployment improved the visibility of the SC, however, only depth improves the SC agility. By contrast, other studies (Khan *et al.*, 2023; Schmidt and Wagner, 2019) have highlighted the potential drawbacks of adopting blockchain, such as failure to process large transaction data, high energy consumption, high investment risks, fewer SC networks and context-dependent applications. Furthermore, Jellason *et al.* (2024) reported concerns against BCT over the disclosure of trade secrets, poor protection against incomplete or inaccurate information, economic and technical challenges, high transaction and information management costs, willingness to pay for the technology, trust in the technology and governance-related issues. However, technological barriers to blockchain-based technology implementation, such as low access to technology, lack of scalability, inadequate expertise and complexity, can be overcome through IT infrastructure development and education. Privacy-related concerns, such as data breaches and sensitive business information, require the involvement of countries, governments, regulatory bodies, stakeholders and consumers. Overall, the BCT showed promising traceability and visibility to enhance the SCR.

4.3.3 Collaboration and integration

During the pandemic period, technological innovation demonstrated how SC is increasingly reliant on DTs to improve the overall functioning of the SC network (Das *et al.*, 2022b). Distance collaboration tools such as AR enabled by telepresence technologies relaxed firms with greater digital maturity and automation through the integration of I4.0T during COVID-19 (Narayanamurthy and Tortorella, 2021). The pandemic period increased the demand and adoption of I4.0T (Akbari and Hopkins, 2022; Wankhede and Vinodh, 2023) so that higher levels of modularisation, flexibility (Hald and Coslugeanu, 2022), resilience and performance (Balakrishnan and Usha, 2021) were obtained. The lower the

Figure 4 Dominant technologies



Source(s): Authors' own work

costs of changes, the higher the resilience during disruption periods (Alexopoulos *et al.*, 2022). However, firms are concerned about human interactions when operating remotely, as well as the budget required to transition to advanced technologies such as IoT, BDA, social media and AI (Jefroy *et al.*, 2022; Matthews *et al.*, 2022; Van Der Vegt *et al.*, 2015). Humans play a crucial role in major sectors like health care, manufacturing, logistics and public service. However, the adoption of technology as a countermeasure against COVID-19 reduced workforce demand in public transport, hotels, stores and distribution. Therefore, ensuring human presence is essential for sustainable digital transformation.

Ivanov's (2021) study on BDA, AI, BCT, track and trace systems, early warning systems and digital platforms and collaborative suppliers' portals showed collaborative problem-solving capabilities with different stakeholders, disruption problem analysis, recovery way-outs, real-time recognition of supply risks and early detection of supply risks. BDA demonstrated its potential for efficient humanitarian response activities, particularly in the areas of real-time information flows and communication (Kumar *et al.*, 2022). According to our investigation, the disruptions negatively impacted collaboration and integration. However, technology played a crucial role in overcoming these challenges through high-quality information, ultimately leading to improved SCRs.

4.3.4 Automation and efficiency

I4.0 technology aims to boost industry productivity and efficiency by shifting traditional production and SC paradigms (Dieste *et al.*, 2022; Malacina and Teplov, 2022). Successful implementation of IoT, cloud services and BDA in manufacturing firms can lead to high performance, automation and decentralised decision-making in SC (Nayernia *et al.*, 2022). However, I4.0 technology layers and levels of adoption are required (Frank *et al.*, 2019). Raja Santhi and Muthuswamy (2022) categorised technological implementation challenges as technical, socio-cultural, administrative and process. In their literature analysis, technical difficulties include scalability, compatibility with existing infrastructure, technological complexity, a high degree of computerisation, unwillingness to share data, security and privacy: standardisation, investment cost, management support and environmental challenges as financial difficulties. The technological process challenges include a lack of skilled professionals, implementation procedure details and immaturity. On the contrary, employee resistance, relative advantages, market uncertainty, fear of change and lack of cooperation between SC partners are socio-cultural challenges. Based on the four categorical paradox theory and their intersection, the main paradoxical tensions existing in I4.0T implementation are learning, organising, belonging and performing (Dieste *et al.*, 2022). Rad *et al.* (2022) presented I4.0 technologies' benefits, challenges and success factors to SC performance. This gives a foundation and structural perspective for upcoming technological features.

Automated SCs could be made possible by technology advancements, allowing control towers to manage supply and demand risks by using higher degrees of awareness. Research can support SC automation advancement by creating better decision-making frameworks to assess and consider various technologies (Van Hoek, 2020). Synchronising business processes with SC networks in a chaotic environment, companies' technological capability for information sharing enhances SCR (Chatterjee and Chaudhuri, 2022). There are research outputs related to the impact of disruptions on SC performance using simulation models (Ivanov and Dolgui, 2021). However, current technological progress lacks a real-time simulation model for humanitarian SCs. The application of technologies in emergency response operations requires proper assessment measures through simulation models to apply in humanitarian activities, as humanitarian activities, particularly emergency response operations, are sensitive and demand better accuracy.

The competitive dimension and technological position of the firm in the SCs make it difficult to optimise the operation and

SCs during turbulent periods. Globalised competition and integrated SCs require higher effort, cost and cooperation with suppliers. And the limitation of technological infrastructure makes the integration between firms challenging and high transaction costs. However, the COVID-19 pandemic compelled organisations to the optimum to use the available resources and technologies such as blockchain, AI and the IoT for the improvement of efficiency and performance within an SC (Rajesh, 2022). The adoption of automated technologies such as AI helps to increase SCR and sustainability by improving real-time inventory management, optimising production and stocks, optimising logistics operations, allowing alternative purchasing scenarios, balancing supply and demand planning and production, increasing SC traceability and bringing top management support (Kazancoglu *et al.*, 2023). AI-assisted large firms during the COVID-19 pandemic by automating the delivery system to overcome transport cost escalations and delivery delays.

4.3.5 Analytical and innovative capability

Organisations with AI analytical capabilities, during disruptions in information sharing (Chatterjee and Chaudhuri, 2022; Kazancoglu *et al.*, 2023; Van Hoek, 2020) and technical support among SC partners are critical for better alliance management capabilities (Dubey *et al.*, 2021a). According to their argument, as an SC enabler, AI analytical capabilities affect operational and financial performance due to its capacity to reduce working capital, maximise return on capital used, enhance product quality, improve product delivery and increase inventory turnover ratio. The use of AI, machine learning and data analytics helps to enhance risk management capability (Hald and Coslugeanu, 2022; Ivanov and Dolgui, 2021). Researchers (Sangeetha *et al.*, 2022; Van Der Vegt *et al.*, 2015) argue that the disadvantages of technologies stem from the significant investment capital required. Nevertheless, the cost associated with technology is essential for building resilient SCs. Technology cannot improve with experience without human involvement. In addition, technology may increase unemployment (Choi *et al.*, 2022), negatively impacting a country's development. Business Data Analytics has revolutionised business operations, but there is a research gap on how organisations should adopt and use it for strategic objectives. Understanding Business Data Analytics linkage between knowledge assets, agility and performance is crucial for competitive advantages (Park and Singh, 2023). Ivanov and Dolgui (2021) further investigated the importance of data analytics to improve the resilience of SC operations and disruption risks using large data.

Zahoor *et al.* (2024) explored how DTs improved the dynamic capabilities of small and medium enterprises (SMEs) and enabled them to provide personalised solutions to their customers and other stakeholders during the COVID-19 pandemic. The IoT offers creative ways to handle risks and challenges, resulting in tangible financial gains due to increased SCR and transparency. The combination of IoT, AI and machine learning helps to identify suppliers during the disruption period (Hald and Coslugeanu, 2022; Spieske and Birkel, 2021). The Internet of People enabled SMEs to seize the opportunity to develop value-creating capabilities, make use of underused resources (Eslami *et al.*, 2024) and diversify business networks and new markets. Eslami *et al.* (2024) discovered that I4.0 DTs improve the impact of SC agility on financial performance. AI and BDA provide early warning systems and detect bottlenecks in the SC helping to take proactive measures. BDA showed the potential to determine the right manufacturing capacity and safety stock levels during the COVID-19 pandemic (Spieske and Birkel, 2021).

Technological capabilities assist organisations in understanding current disruption recovery and future interruption mitigation capabilities (Naz *et al.*, 2022). In uncertain and disruptive situations, disaster relief workers require collaboration and information sharing to resolve specific cases. The role of emerging technologies such as AI-driven BDA capabilities for improving information alignment and collaboration, which are elements of agility (Altay *et al.*, 2018), is crucial (Dubey *et al.*, 2021b; Kazancoglu *et al.*, 2023). Our findings are consistent with Sharma A. *et al.*'s (2020) work, which suggests that SCs must be modelled in an agile, adaptable and forward-looking way to respond to unexpected disruptions. However, most companies in the SCM prefer to adopt different technologies in finance (Choi *et al.*, 2023), information and risk management applications to provide their services and products to customers. In SC finance, technologies such as information technologies, blockchain and AI are used in different contexts. The evolution of financial technology companies during the pandemic period is due to the fragmented use of technology in SC financing. This might be due to security concerns, the need for customised technologies, the need for specific technological features that determine competitive advantages and the lack of information about existing technology. However, this creates integration and collaboration challenges between industries. Using I4.0T throughout the SC network and value chain is better than using them separately. Other studies (Frederico *et al.*, 2023) showed that I4.0T does not support interoperability, the capability of systems to transact with other systems.

Based on the current trends and upcoming developments, the authors designed future technological aspirations (Figure 5) that depict the role of technology in building RSC. Figure 5 combines both commercial and humanitarian SC activities based on their technical and sustainable (Kazancoglu *et al.*, 2023) development goal requirements.

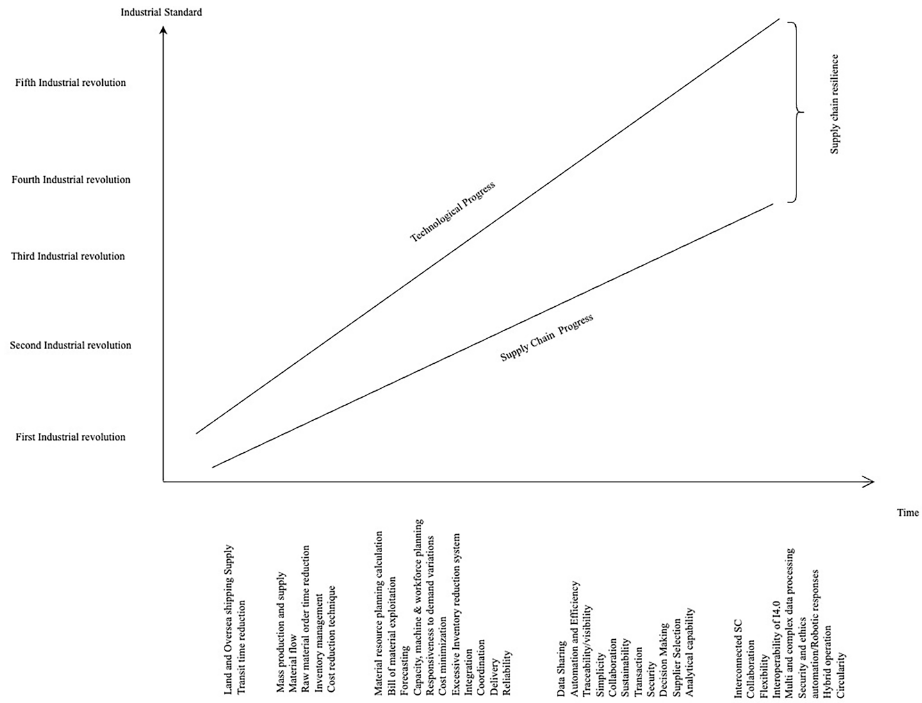
We hope that this complete approach will help researchers use it as a conceptual framework for future empirical work in SCRs and will assist practitioners in successfully adopting customised technology for creating and improving SCRs.

5. Research needs and discussion

The COVID-19 pandemic has accelerated the development of resilience and survivability in industries, enabling them to withstand significant disruptions. Drawing from the results of our sample analysis and the growing volume of research requests received by research journals, we proposed possible directions for future research.

The paper has time-horizon and scope-related limitations. Firstly, this SLR is performed during the COVID-19 maturation period. However, extending the study period could help include a broader range of knowledge, which is a limitation of this study. Secondly, this study considers only the role of

Figure 5 Technological progress and supply chain resilience



Source(s): Authors' own work

technology in developing RSC systems. This study focuses on a period of disruption in evaluating the role of technology, despite considerable existing literature on technology's usage across different periods. However, future researchers can provide further new and deep insights into the topic by including upcoming studies, findings and other evidence. Finally, in this SLR, it is possible that the depth of understanding and interpretation of the analysed literature can sometimes be overlooked. To ensure accurate understanding and interpretation, we thoroughly examined the existing literature through a comprehensive literature review.

5.1 Technological collaboration and integration

Coordination and information exchange issues were the main challenges within the SC systems (Kumar and Kumar Singh, 2022). In humanitarian SC activities, volunteers and humanitarian experts use DTs to communicate both one-way and two-way, coordinate resources and conduct overall response activities (Durugbo *et al.*, 2022). Technology greatly assists fundraising activities compared to traditional systems, as it simply and dominantly reaches every corner of the world. DTs like blockchain, AI and BDA have shown significant potential in overcoming disruptions like COVID-19, promising future transport (Choi and Shi, 2024) and security systems. Investigating the combined effect of various technologies in the SC is crucial for enhancing SCR, ensuring effective emergency response and enhancing customer satisfaction. However, the combined effect of technology with operations management tools for SCR enhancement remains open for further studies. For instance, in agricultural SC, AI applications, several electronic machines and technology platforms, namely big data, IoT, cyber-physical systems, etc. are interconnected. In the agricultural SC, the descriptive application of AI allows farmers with large herds to understand the behaviour of individual cows, which improves milk yield (Olsen and Tomlin, 2020), whereas Leme *et al.* (2020) proposed the use of BCT to monitor the overall health of cows. Thus, future research and innovation could direct the technological integration between firms to avoid the use of various technologies for the same application in SC systems. The model research question could be: How can the technological features integrate with the practical aspects and improve the current system, as well as how could they mitigate future challenges and risks? Which technology or technologies have the potential to solve coordination problems during disruption times? Future research can also explore the use of simulation models in humanitarian activities, focusing on how they enhance technology effectiveness; improve supply forecasting, distribution and coordination; and overcome infrastructure challenges.

5.2 Data privacy and technological ethics

Security risks can be mitigated through data protection measures. Data privacy, confidentiality infringement and tracking violations are increasing, posing a threat to SC integrity (Wang *et al.*, 2021b) by allowing employees to exploit data for cyberattacks, bullying and defamation (Verma *et al.*, 2023). Most privacy concerns are the result of transparency and visibility in SC processes. Technological misuse is primarily caused by factors such as easy entry, subscription requirements, weak hacking spots, lack of ethical training and government regulations in SC, which are allowing companies to exploit opportunities. However, unethical firms' technological practices can result in trust issues, market losses and sustainable business competitiveness. The introduction of Bitcoins (cryptocurrency technologies) into the finance operations interface (Choi *et al.*, 2022) facilitates transactions and allows easy entrance for large numbers of players in digital banking, which raises security concerns such as cheating, the weakening of governance structures and threats to the traditional banks that have served the SC. Thus, future research can investigate how individual loyalty impacts the benefits of technology in SC firms and their societal concerns. How does technology react to privacy issues and data breaches to ensure information gathering, analysis and sharing?

5.3 Technological standards and architectural references

Common technological standards that help to measure performance, quality and customer values are vital for technological development. These standards identify the impact of the outstanding performance of technologies. The acceptance of technology in the industry depends on the standardisation and regulations set to perform a specific task and withstand security challenges. Studies (Ardolino *et al.*, 2022; Rad *et al.*, 2022) have found that the socio-economic effects of I4.0 across various countries are hindered by a lack of industry standards. Mass production applicability of AM technologies is hindered by limited design standards. Different materials require different AM technologies (Olsen and Tomlin, 2020). This leads to high processing costs and monopolistic producers. Future research can deal with the role of technology standardisation in building resilient and sustainable SCs. How do technology standards help with SC traceability? Does technology standard have a significant impact on employee innovation performance? Architectural reference is crucial for setting technical details of technological setups, which determines the misuse and security concern of a technology. Thus, it is not sufficient to set the technical details of technologies to study their impact on SC performance alone. Therefore, future research is expected to measure the technical details of the technologies from a business perspective. To fully implement, benefit from and build a resilient SC system using DTs, the SC requires sharing data among the SC stakeholders and governments, training and similar standards (Tiwari *et al.*, 2024).

5.4 Technological automation

Technology introduces new systems, processes, knowledge, skills and culture, which disrupts existing organisational processes and integrity and exposes operational inefficiencies for some time (Tiwari *et al.*, 2024; Van Der Vegt *et al.*, 2015). The introduction of new technologies into organisations during the pandemic affected human resources because of the complexity of work due to the integration of technology and digitalisation. Employees expect to see technologies reduce their effort and increase their productivity instead of being a threat because, in most cases, it is believed technology has no significant impact on employee performance. Thus, it is vital to create a comprehensive understanding of the benefits, capabilities and limitations of the new technology before deploying it in any organisation. For instance, the COVID-19 pandemic urged the transition from human operation to a higher automation level and digitalisation in a container terminal (Zhou *et al.*, 2022); however, most technologies implemented at the port are meant to improve efficiency or reduce human contact, yet they have not changed the mode of operation. Relevant research on these issues is scarce at this moment. What is the cost of technology compared to labour? Developing countries face challenges in SC integration, resilience, sustainability, cleaner production and circular economy practices due to limited technology adoption, necessitating further studies on I4.0 DTs. An interesting research question could be: What is the potential of technology in improving developing countries' SCs beyond controlling, monitoring and connectivity?

5.5 Technological dominance

The adoption of I4.0T in logistics and SCs and the dominance of a particular technology are far from advanced utilisation due to different factors (Dieste *et al.*, 2022; Hopkins, 2021). The first obstacle is the need for businesses to actively demand change and incorporate new practices, which often requires abandoning their previous methods, ensuring confidentiality and making a separate effort. The second problem is that the adoption of technology and its integration take longer than anticipated because of factors such as finance, readiness, security, operational complexities and skilled professionals (Murtaza *et al.*, 2004; Wankhede and Vinodh, 2023). The third barrier is the absence of regulators and legislators who can set standards for technological innovations while protecting company information, customer data and risks. To shift the SC paradigm, AI and BCT have shown the most significant technological features, followed by BDA, automation and IoT (Figure 3). Research on technological dominance could be: Which technology specifically or a combined technology overtakes visibility, traceability and tracking roles? Which technology or technological feature has the potential to process large and complex data?

6. Implications

Existing literature is scattered across research streams, highlighting a gap in understanding the potential of technologies to improve SCR within SC networks. As a result, it becomes essential to conduct this SLR to bring the disparate body of information together, offer a thorough framework for directing future research and its practical application and pinpoint present trends and opportunities.

6.1 Theoretical implications

Our analysis has uncovered potential theoretical implications that could offer valuable insights. Firstly, this SLR adds to the existing body of knowledge by expanding the understanding of the role of technology during disruption times and which features of the technology are shifting the paradigms of the SC systems. The technological features are changing the way businesses operate, compelling the SC to depart from the traditional system to be resilient and sustainable in both normal and disruptive environments (Birkel *et al.*, 2023). This aids in identifying the implications of these technologies for resilient SC systems, encouraging academicians and technologists to work on them as existing technologies are updated or replaced with new ones.

Secondly, this study foresees disruptive technological breakthroughs that may change the SC paradigms based on popular technological features that help in overcoming disruptive events and building resilience in the SCs. This study found that AI, BCT, BDA, IoT and automation technologies are among the potential technological innovations the SCs are expected to implement in the future, which is consistent with the work of Akbari and Hopkins (2022). This technological study on the development and needs of upcoming technological features aids researchers in comprehending how technology will influence SC systems in the future.

Thirdly, previous research has concentrated on the adoption, benefits, barriers, implementation and financial aspects of technologies in SCs (Khan *et al.*, 2023). However, this study adds to the body of knowledge by revealing a significant gap between technological and SC progress. Studying the technological progress and the SC gap provides the conceptual foundation for future discussions about developing a resilient SC system for disruptions that can adapt, respond and recover from SC shocks (Kaliyan *et al.*, 2023).

6.2 Practical implications

We highlighted the significance of technology in logistics and SC activities, emphasising its potential for improved visibility, transparency, collaboration and efficiency (Kazancoglu *et al.*, 2023). We also underscore the need for I4.0T and improved data-driven forecasting (Dieste *et al.*, 2022) during disruption and economic sanctions.

Firms that do not adopt technology cannot develop long-term SCM, performance or resilience, and they risk failure during a disruptive event (Kazancoglu *et al.*, 2023). This study provides a broad range of understanding about the role of technologies concerning logistics and SC activities. As a result, it assists logistics and SC professionals and owners in evaluating and selecting dominant, feature-rich and compatible technologies.

The framework highlights the role of technology in enhancing SCR, allowing practitioners to select the appropriate technology for improved visibility, transparency, collaboration, integration, efficiency, analytical capability or information processing and sharing based on their business model.

Most I4.0T, according to the SLR, are still in their infancy and lack mature technology that integrates various technological features, which could be due to finance, readiness, security and skilled professionals (Dieste *et al.*, 2022; Ivanov, 2021; Zahoor *et al.*, 2024). Although I4.0T claim to collect, manage and analyse data, COVID-19 has shown how the SC system has experienced an unprecedented level of disruption, such as limited access and an inability to process large and complex transaction data. Improving the ability to use big transaction data in a short period and data-driven forecasting helps to bring resilience to SCs. This offers technologists, digitalisation managers, SC managers and related practitioners the opportunity to improve the technology for better implementation.

Furthermore, given the scarcity of studies on the role of technology in resolving SC issues during the Russia–Ukraine conflict, we emphasised the need for improved technology implementation amidst economic sanctions.

7. Conclusion

The global SCs, the driving force behind globalisation and a crucial economic channel were affected by disruptions that are both combined and successive events, such as the COVID-19 pandemic, the China–USA trade war, the conflict in Ukraine and the heavy sanctions on Russia (Estrada and Koutronas, 2022). To address these issues, mostly I4.0 was used to run manufacturing plants, meet raw material shortages and reduce the impact of inflation. The rapid technological changes instruct the SC system to face a new paradigm, to make the SC more resilient, enabling better response to future crises. Based on this SLR, it is found that the current technology requires a range of new features, such as collaboration, connectivity, hybridised systems, interoperability and security. These findings suggest that a new, more modern technological shift is needed that reflects the latest developments in Industry 5.0 (Jefroy *et al.*, 2022). The SC network is strong and crisis-resistant because of technology use (Das *et al.*, 2022b). The study provides a framework for future researchers to explore current and future technological requirements. The study gives ideas holistically on the full technological features and/or requirements for the logistics and SC management sector. Technology enhances resilience but requires organisations to balance its benefits with potential drawbacks like dependency, complexity, costs, security risks, skill gaps, information overload and reduced human interaction.

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