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Meta-review of data science in industry 4.0/5.0 for enhancing supply chain resilience

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Abstract: In an ever-evolving landscape shaped by Industry 4.0 and emerging Industry 5.0 paradigms, the importance of resilience in supply chains cannot be overstated. For this reason, the aim of this study is to conduct a meta-review on enhancing resilience in supply chains 4.0 and 5.0, focusing on data science-based approaches to offer a comprehensive overview and high-level synthesis of the current state of knowledge. Our research has shown that the majority of studies employ broad criteria for publication classification and analysis, concentrating on factors such as publication years, academic disciplines, journals, geographical distribution, and research types. However, our approach takes a more specific methodology, utilizing the CIMO method, which emphasizes context, intervention, mechanism, and outcome components. While the prevailing focus of existing literature is on Industry 4.0-based supply chain contexts, with limited attention to Industry 5.0, the most analysed technologies include blockchain, IIoT, IoT, cloud computing, digital twins, wireless sensor networks, 3D printing, and cyber-physical systems, among others. Notably, resilience enhancement in the reviewed studies predominantly relies on artificial intelligence, machine learning, data analytics, big data, and, to a lesser extent, deep reinforcement learning and predictive analysis.

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1 Introduction

The evolution of technological systems has facilitated the adaptation of supply chain (SC) processes to enhance resilience, garnering interest across various economic sectors. In light of this, a meta-review is undertaken to offer a comprehensive overview and high-level synthesis of the current state of knowledge regarding the enhancement of resilience in 4.0/5.0 SC through data science mechanisms.

The remainder of the paper is structured as follows. Section 2 describes the review methodology. Section 3 presents the main findings of the literature review, together with the discussion and conclusions.

2 Review methodology

In this paper we follow the CIMO methodology (context, intervention, mechanisms, and outcome) proposed by Denyer & Tranfield (2009). This involved establishing a search string based on these criteria and applying it to the Scopus database:

Context: "Supply chain" OR "Manufacturing" AND "Industry 5.0" OR "Fifth industrial revolution" OR "Industry 4.0" OR "Fourth industrial revolution" OR "Industry 4.0/5.0" OR "Industry 4.0 & 5.0".

Intervention: "Data *" OR "Digital supply chain" OR "Visualisation approaches *" OR "Multi-criteria analysis *" OR "Regression analysis *" OR "Social network analysis *" OR "Data envelopment analysis *" OR "Data science" OR "Data mining" OR "Data analy *" OR "Data engineering" OR "Machine learning" OR "Business intelligence" OR "Statistical methods" OR "Big data" OR "Statisti-cal".

Mechanisms: Resilience" OR "Resilient" OR "Resilien* " OR "Resiliency".

Outcome: "adapt*" OR "recover*" OR "prepared*" OR "proactive" OR "robust*" OR "performance" OR "restor*" OR "prevent*".

Following the retrieval of results, acceptance criteria were established, including English language, publication years from 2011 onwards, and document type limited to reviews for the present meta-review. This methodology ensured the retrieval of relevant literature, facilitating a focused analysis of the enhancement of resilience in Industry 4.0/5.0 SCs through data science mechanisms, as outlined by the CIMO framework.

3 Discussion and conclusions

Out of the 10 articles reviewed, most of them use general criteria for the classification and analysis of publications such as publication years, academic disciplines, journals, geographical distribution, sector and application areas, research types, among others. However, this meta-review focuses on more specific criteria following the CIMO methodology (Denyer & Tranfield, 2009). The CIMO methodology encompasses the following components: (i) context: the systems under investigation; (ii) intervention: here, the focus is on analysing the impacts of specific capacities, actions, or activities; (iii) mechanisms: this part explores the approaches that relate interventions with outcomes; and (iv) outcomes: the effects of the intervention, including both intended and unintended consequences. Taking this into consideration, our research seeks to investigate into the area of improving the resilience (intervention) of 4.0/5.0 SCs (context) through data science approaches (mechanisms), with the overall objective of anticipating disruptions and, in the event of an impending crisis, to carry out a rapid and efficient recovery process (output). Thus, Table 1 summarises the main objectives of the reviews aligned with the objective of this research.

Table 1 Objectives of the publications included in the meta-review

Reference	Objective
(Ivanov et al. 2018)	To investigate the applicability of control theory to engineering and management problems in SC operations, particularly in the context of Industry 4.0 networks.
(Corallo et al. 2022)	To analyse how the existing state of the art deals with cybersecurity awareness in the context of industrial internet of things (IIoT).
(del Real Torres et al. 2022)	To review the current state and potential of intelligent manufacturing technologies, particularly focusing on deep reinforcement learning (DRL) algorithms, and their application in enhancing manufacturing processes' resilience and adaptability.
(Jayashree et al. 2022)	To conduct a literature review on I4.0 technologies, SC, and their interaction with the COVID-19 pandemic. This aims to explore how emerging technologies can enable more responsive and resilient SCs during emergencies such as the COVID-19 outbreak.
(Leng et al. 2022)	To explore and analyse the capabilities of distributed blockchain middleware in minimising the risk of a single point of failure within the context of resilient manufacturing in I5.0.
(Raja Santhi & Muthuswamy 2022)	To explore the role of I4.0 technologies in enhancing SCRes and sustainability. This involves understanding how modern technologies can mitigate challenges and uncertainties in SC management, including those arising from global events like the COVID-19 pandemic, wars, and natural calamities.
(Sheth & Kusiak 2022)	To enhance the resilience and adaptability of manufacturing enterprises within the context of I4.0/5.0. This involves transitioning from reactive to proactive systems to better respond to disruptions and challenges in the SC and manufacturing processes.

Reference	Objective
(Chauhan et al. 2023)	To develop a framework for understanding SCRes based on a systematic literature review and to identify gaps and areas for further research in the field.
(Marinagi et al. 2023)	To investigate how key performance indicators (KPIs) for creating a resilient SC are influenced by I4.0 technologies. Specifically, the study aims to identify which Industry 4.0 technologies can improve SCRes and how these technologies impact the KPIs associated with SCRes.
(Agarwal, Malhotra & Swami 2024)	To examine the evolving landscape of smart technology adoption in the context of SC management post-pandemic. This involves conducting an exploratory systematic literature review to identify key themes and trends related to smart technology adoption, particularly focusing on supply chain resilience, digital transformation, enhanced visibility, predictive analytics, and sustainability considerations.

The reviews found, based on the review methodology described in Section 2, are analysed according to the CIMO methodology, as shown in Table 2.

Table 2 CIMO meta-review

Reference	Context	Intervention	Mechanism	Output
(Ivanov et al. 2018)	SC 4.0	SCRes	Artificial intelligence (AI) and big data (BD)	A comprehensive framework that systemizes different streams in the application of control theory to operations and SC management and engineering for the prediction of failures and detection of anomalies to optimize planning and decision making.
(Corallo et al. 2022)	Smart manufacturing 4.0		BD and data analytics (DA)	Prevention of damage to daily business operations, operational shutdowns, equipment damage, financial losses, intellectual property losses, and health and safety risks.
(del Real Torres et al. 2022)	Smart manufacturing 4.0 and 5.0	Operational resilience	AI, DRL and machine learning (ML)	Anticipating product demand, identifying potential disruptions in the SC and optimising production and distribution planning
(Jayashree et al. 2022)	SC 4.0	SCRes	AI, DA and ML	Optimisation of inventory levels through real-time data analysis, leading to improved SC competitiveness. It contributes to risk mitigation, error detection, data agility, and privacy.
(Leng et al. 2022)	SC 5.0	System resilience	AI, BD and ML	A comprehensive review of secure blockchain middleware for decentralised IIoT towards I5.0. It includes an analysis of security issues in conventional IIoT solutions, the advantages of blockchain middleware, and a proposed architecture for secure blockchain middleware.
(Raja Santhi & Muthuswamy 2022)	SC 4.0	SCRes	AI, BD, ML and predictive analytics	The expected outputs include improved SCRes, agility, transparency, and sustainability. By adopting I4.0 technologies, organisations aim to facilitate rapid adaptation to changing market demands, reduced lead times, and proactive mitigation of

Reference	Context	Intervention	Mechanism	Output
				disruptions, ultimately leading to a customer-centric and demand-driven SC.
(Sheth & Kusiak 2022)	Smart manufacturing 4.0	System resilience	BD, data mining (DM), and ML	Implementation of Complex Adaptive System theory and AI to transform manufacturing enterprises into proactive, adaptive systems capable of responding to disruptions and achieving long-term sustainability and competitiveness.
(Chauhan et al. 2023)	SC 4.0	SCRes	AI and BD analytics	A conceptual framework that illustrates the role of SC network design, resilience measures, and the linkage between SCRes, risk management, sustainability, and digitalisation. It also emphasizes the importance of managerial innovation, co-creation, and the use of AI and BD analytics to predict potential SC disruptions.
(Marinagi et al. 2023)	SC 4.0	SCRes and its constituent elements	AI and BD	The identification of the most important constituent elements of SCRes, the Industry 4.0 technologies that improve the SCRes elements, and the KPIs that enhance SCRes.
(Agarwal, Malhotra & Swami 2024)	SC 4.0 and 5.0	SCRes	AI, BD, DA, DM and M.	The transformation of SC practices to better withstand future disruptions, adapt to changing market dynamics, and deliver value to customers in a digitalised and interconnected world.

The majority of reviews focus on a context of SC based on I4.0, while to a lesser extent, research aims at I5.0. I5.0 is a more emergent concept, which is why research to date has primarily centred on the fourth revolution. Among the technologies related to I4.0 and I5.0, the following, in order, are the most analysed: blockchain, IIoT, internet of things (IoT), cloud computing, digital twins, wireless sensor networks, 3D printing, and cyber-physical system, robotics and cobots. Since the primary context is SC, the most analysed intervention is SCRes, although there are reviews focused on operational resilience and system resilience as well. Furthermore, one of the analysed articles also considers the following components of the resilience capacity: SC configuration/SC network design, redundancy, flexibility, visibility, collaboration, agility, situation awareness, information sharing, SC risk management, culture, security, robustness, risk management, knowledge management, and velocity. Regarding the mechanisms, it is noteworthy that the enhancement of resilience in the analysed reviews is achieved through: AI (28%), ML (24%), DA (21%), BD (21%), DRL (3%), and predictive analytics (3%), with the percentage representing the frequency of appearance of these mechanisms in the studies examined.

The outputs highlight the critical role of advanced technologies and strategic frameworks in strengthening SCRes and navigating the complexities of the modern business landscape. A holistic framework that leverages control theory in operations

and SC management emerges as a cornerstone, enabling predictive maintenance, anomaly detection and informed decision making to mitigate operational risks and improve business continuity. This proactive approach protects against disruptions and also prevents damage to daily operations, equipment, finances and intellectual property, fostering a culture of resilience and sustainability. Moreover, the integration of I4.0 technologies, such as secure blockchain middleware and complex adaptive systems powered by AI, promises to revolutionise SC dynamics, ensuring transparency, agility and responsiveness to market demands. In addition, conceptual frameworks emphasising SC network design, digitisation and innovation underline the interconnection between SCRes, risk management and sustainability, providing a roadmap to achieve competitive advantage and customer focus in an increasingly digitalised environment.

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