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Unveiling barriers to Industry 5.0 adoption in supply chains: a DEMATEL approach

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Abstract

Purpose – The objective of this research is to investigate the barriers impacting the integration of Industry 5.0 (I5.0) in supply chain sustainability. By understanding these challenges, this study aims to provide valuable insights that can guide organizations in successfully implementing the transformative potential of I5.0. The ultimate aim is to improve operational efficiency and advocate for sustainable practices within supply chains.

Design/methodology/approach – Research has used industry expert interviews, a comprehensive literature review and the decision-making trial and evaluation laboratory approach for analysis. Industry expert interviews serve to capture first-hand insights from professionals well versed in the field, providing practical perspectives on the barriers to I5.0 adoption.

Findings – This study identifies technological challenges, organizational barriers, regulatory impediments and economic constraints as pivotal factors inhibiting the widespread adoption of I5.0 in supply chain sustainability.

Research limitations/implications – This research serves as a foundation for future investigations into overcoming barriers to I5.0 adoption, guiding scholars and practitioners in refining strategies for successful implementation.

Practical implications – The findings offer practical insights for organizations aiming to adopt I5.0, informing decision-makers on key challenges and facilitating the development of targeted strategies to overcome them.

Social implications – The social implications lie in fostering sustainable business practices through the adoption of I5.0, contributing to environmental responsibility and societal well-being.

Originality/value – This research contributes original insights from practitioners, policymakers and researchers in navigating the complex landscape of I5.0 adoption, ensuring meaningful contributions to both academia and industry.

Keywords Barriers, Organizational barriers, Industry 5.0, Regulatory barriers, DEMATEL, Sustainable supply chain practices, Technological barriers, Economic barriers

Paper type Research paper

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Introduction

Industry 5.0 (I5.0), also known as the "human-centered" industrial revolution, represents the integration of advanced technologies, such as artificial intelligence, Internet of Things (IoT), big data analytics and robotics, with human intelligence and skills in the manufacturing and supply chain processes (Buchholz, Albers, Lautenschläger, & Kinkel, 2021; Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014). This new paradigm aims to create more efficient, flexible and sustainable production systems by combining the strengths of humans and machines (Mourtzis, Vlachou, Georgoulias, & Xanthakis, 2019).

In the context of sustainable supply chain practices, I5.0 holds significant promise. It offers opportunities to optimize processes, reduce waste, improve resource utilization, enhance product quality and enable real-time monitoring and decision-making (Barquet, Pereira-Klen, Rozenfeld, & Lopes, 2020; Chauhan, Kumari, & Kumar, 2021a, Chauhan, Saini, & Chauhan, 2021b). By leveraging I5.0 technologies, organizations can enhance their environmental performance, promote social responsibility and achieve long-term economic viability (Aslam, Khan, Khan, & Khan, 2020; Raj, Dwivedi, Rana, Chen, & Singh, 2021).

However, the adoption of I5.0 in sustainable supply chain practices is not without its challenges. Organizations face various barriers that hinder their ability to fully embrace and implement I5.0 technologies. These barriers span technological, organizational, regulatory and economic dimensions, and addressing them is essential for successful adoption and realization of the benefits offered by I5.0 (Dwivedi, Rana, Jeyaraj, Clement, & Williams, 2020; Oksuz, 2020; Singh, El-Nasr, & Gupta, 2020; Rame et al., 2023).

This literature review aims to explore and analyze the key barriers faced by organizations in adopting I5.0 and achieving sustainable supply chain practices. By understanding these barriers, organizations can develop effective strategies to overcome them and pave the way for successful implementation.

Various types of challenges that organizations encountered are related to interoperability, information technology (IT) infrastructure, connectivity and cybersecurity (Hsieh, Lin, & Yu, 2020a; Jing, Cai, Huang, & Li, 2020a; Huang, Chu, Ho, & Lee, 2021a). The organizational barriers include resistance to change, lack of awareness, skills gap and organizational culture (Oksuz, 2020; Johansson & Sundström, 2020). Regulatory barriers encompass inadequate frameworks, legal uncertainties, compliance challenges and ethical considerations (Singh et al., 2020; Nofal, Al-Nuaimi, & Aloudat, 2020; Srivastava, 2021; Moore & Wong, 2020). Also economic and financial barriers include such as high costs, uncertain return on investment and financial constraints (Palacios-Argüello, van Hoek, & Diaz-Padilla, 2021).

By examining the existing literature on these barriers, this review provides insights into the challenges organizations face when adopting I5.0 in sustainable supply chain practices. It highlights the importance of addressing these barriers to unlock the full potential of I5.0 and create sustainable, resilient and efficient supply chains.

Despite the global movement toward I5.0, there is a notable dearth of research focused on understanding the barriers to implementing I5.0 specifically within the supply chain function, which can help in achieving sustainable goals. To address this research gap, this paper aims to investigate the following research issues:

RQ1. What are the barriers to I5.0 implementation in the Indian supply chain?

This research question seeks to identify and examine the specific challenges and obstacles faced by organizations in India when adopting I5.0 technologies and practices within their supply chain operations. By exploring these barriers, the study aims to shed light on the factors that hinder successful implementation and hinder the realization of the benefits offered by I5.0:

RQ2. What is the contextual relationship among these barriers?

This research question aims to explore the interconnections and contextual relationships among the identified barriers to I5.0 implementation in the Indian supply chain. By understanding the relationships between these barriers, the study seeks to provide insights into how they interact, influence each other and potentially exacerbate or mitigate their impact. This understanding of the contextual relationships can help organizations develop comprehensive strategies to address multiple barriers simultaneously and enhance the overall effectiveness of I5.0 implementation efforts.

By addressing these research issues, this study aims to fill the gap in the existing literature by providing valuable insights into the barriers to I5.0 implementation in the Indian supply chain. The findings of this research will contribute to the body of knowledge on I5.0 and supply chain management, enabling organizations to make informed decisions and develop targeted strategies to overcome these barriers. This will lead to the future study on the achievement of sustainable goals by facilitating the successful adoption and integration of I5.0 technologies within the Indian supply chain context.

Literature review

The concept of sustainable supply chain management has gained significant attention in recent years due to the growing recognition that supply chain activities impact not only the economic performance of organizations but also environmental and social aspects. The adoption of advanced technologies such as I5.0 in supply chain management can lead to significant benefits, but it must also be aligned with sustainability goals. This literature review explores the intersection between supply chain sustainability and I5.0, highlighting the opportunities and challenges associated with the integration of these two concepts.

Industry 5.0

I5.0 is the latest stage in the evolution of the manufacturing industry, characterized by the integration of advanced technologies such as artificial intelligence, the IoT and cyberphysical systems into the manufacturing process. The integration of these technologies aims to create a smart factory that is highly automated, flexible and able to adapt to changing demands. The ultimate goal of I5.0 is to create a manufacturing ecosystem that is more efficient, productive and sustainable (Kagermann, Wahlster, & Helbig, 2013). I5.0 represents the anticipated succeeding phase in industrial development, aiming to harness the innovative capabilities of human experts working alongside proficient, intelligent and precise machines (Maddikunta et al., 2022). I5.0 amalgamates organizational principles and technologies to create and oversee operations and supply chains as resilient, sustainable and human-centric systems (Ivanov, 2023).

In summary, I5.0 is characterized by a human-centered approach to technological advancements in the industrial sector which help in sustainable supply chain practices. It aims to balance the present and future needs of both workers and society while prioritizing sustainability. Specifically, I5.0 focuses on optimizing energy consumption, materials processing and product life cycles in a way that aligns with the principles of a sustainable supply chain. This approach emphasizes responsible industrial practices, minimizes environmental impact and promotes efficient resource utilization throughout the supply chain (Barata & Kayser, 2023).

Opportunities for supply chain sustainability in Industry 5.0

Sustainable supply chain management is concerned with balancing economic, environmental and social aspects in the management of supply chain activities (Srivastava, 2007). The economic aspect of sustainability in supply chains is achieved by ensuring that supply chain activities are efficient and cost-effective. The environmental aspect of sustainability involves reducing waste and emissions, sourcing materials and energy from sustainable sources, and ensuring that supply chain activities do not have negative environmental impacts. Finally, the social aspect of sustainability in supply chains involves ensuring fair labor practices, safe working conditions and community engagement (Srivastava, 2007).

The integration of I5.0 technologies into supply chain management presents significant opportunities for achieving sustainability goals. Sustainable supply chains involve balancing economic, environmental and social considerations, and I5.0 can contribute to all three aspects (Srivastava, 2007).

One of the main benefits of I5.0 in supply chain sustainability is the potential to reduce waste and energy consumption. The use of advanced technologies such as artificial intelligence, machine learning and the IoT can enable real-time monitoring and analysis of supply chain data, allowing organizations to identify inefficiencies and waste (Lee & Kwon, 2020). This, in turn, can lead to improved resource efficiency, reduced energy consumption and decreased waste generation (Bhatti, Kumar, & Singh, 2020).

In addition to reducing waste and energy consumption, I5.0 can also promote circularity in supply chains. Circular supply chains involve the reuse, refurbishment or recycling of products and materials, reducing the need for new resources and minimizing waste. The integration of I5.0 technologies such as predictive maintenance and digital twins can enable more efficient and effective product life cycle management, allowing organizations to extend the lifespan of products and materials and promote circularity (Yakovleva, Sarkis, & Sloan, 2021).

Furthermore, I5.0 can enable greater transparency and traceability in supply chains, which is crucial for ensuring responsible sourcing, reducing environmental risks and promoting ethical practices. The use of blockchain technology and smart contracts can enhance transparency and traceability, enabling supply chain stakeholders to monitor and track products from raw materials to the end consumer. This can help organizations to identify and address environmental and social issues such as deforestation, child labor and human rights violations (Scherer & Palazzo, 2011).

Another opportunity for supply chain sustainability in I5.0 is the potential to improve labor conditions and social sustainability. While the adoption of advanced technologies such as automation and robotics could result in job displacement, I5.0 can also create new opportunities for skilled jobs in fields such as data analysis, cybersecurity and software engineering (Brynjolfsson & McAfee, 2014). Furthermore, the use of digital technologies such as virtual reality and augmented reality can improve training and education for workers, enhancing their skills and employability (Schwab, 2016).

Although the integration of I5.0 in supply chain management presents significant opportunities for achieving sustainability goals, it can help organizations to reduce waste and energy consumption, improve resource efficiency, promote circularity, enhance transparency and traceability and improve labor conditions and social sustainability. However, there are several challenges companies are facing to adopt I5.0 for supply chain sustainability.

Barriers for the adoption of Industry 5.0 in SC

The adoption of I5.0 in supply chain (SC) faces several barriers including technological, organizational, regulatory and economic. Understanding and addressing these barriers are crucial for organizations to successfully adopt I5.0 and achieve sustainable supply chain practices. These barriers have been discussed by the various literatures:

- As in I5.0, seamless integration and communication among various systems and technologies are crucial for achieving an efficient and sustainable supply chain. However, the lack of standardized protocols and interoperability poses a significant barrier. Different systems and technologies may have incompatible formats and interfaces, making it challenging to exchange information and collaborate effectively (Hsieh, Lin, & Yu, 2020b). I5.0 heavily relies on robust IT infrastructure and high-speed connectivity for real-time data sharing and analysis. However, inadequate infrastructure and limited connectivity, especially in remote or underdeveloped regions, hinder the implementation of I5.0 technologies. Without proper infrastructure, organizations face challenges in capturing and leveraging data to enhance supply chain sustainability (Jing, Shen, Xia, & Yuan, 2020b). The increased connectivity and data sharing in I5.0 present cybersecurity risks and data privacy concerns. With a greater number of interconnected devices and systems, organizations become vulnerable to cyber threats and unauthorized access to sensitive information. These concerns can significantly impact trust and hinder organizations from adopting I5.0 technologies (Huang, Lin, Zhang, & Zhang, 2021b). I5.0 technologies often require significant investments in hardware, software and workforce training. Upgrading existing systems to support the integration of advanced technologies can be financially burdensome for organizations, particularly those with limited financial resources. The high costs associated with I5.0 adoption can deter organizations from pursuing these technologies (Purwanto et al., 2021).

Organizations may face resistance from employees and stakeholders who are resistant to change or lack the necessary digital skills and readiness to adopt I5.0 technologies. This barrier is particularly prominent in traditional organizations with long-established practices and cultures. Resistance to change and inadequate digital readiness can impede the successful implementation of I5.0 initiatives (Oksuz, 2020). Many organizations have limited knowledge and understanding of I5.0 and its potential benefits. Lack of awareness about the transformative power of I5.0 and its ability to improve supply chain sustainability can lead to a reluctance to invest in these technologies. Organizations need to actively educate themselves about I5.0 to realize its potential and drive adoption (Oksuz, 2020). The successful adoption of I5.0 requires a skilled workforce proficient in emerging technologies such as artificial intelligence, big data analytics and IoT. However, organizations often face challenges in finding qualified talent and providing adequate training programs to upskill their employees. The scarcity of individuals with I5.0-related skills and knowledge hinders the adoption and implementation of these technologies within the supply chain (Adel, 2022a, 2022b, 2022c). Hierarchical structures and resistance to collaboration and knowledge-sharing can impede the integration of I5.0 practices into the organizational culture. I5.0 promotes cross-functional collaboration and data-driven decision-making, which require a more open and collaborative organizational culture. Without a supportive culture and flexible structure, organizations may struggle to adapt to the changes brought by I5.0 (Johansson & Sundström, 2020).

Inadequate regulatory frameworks and policies addressing the adoption of I5.0 and its impact on supply chain sustainability can create uncertainty and hinder organizations' willingness to invest in these technologies. Clear and supportive regulations are essential to provide guidance and assurance to organizations regarding the legal and ethical aspects of

I5.0 adoption (Singh et al., 2020). I5.0 technologies involve the collection and analysis of large volumes of data. Issues related to intellectual property rights, data ownership and liability can create legal uncertainties and disputes. Organizations may be hesitant to adopt I5.0 technologies due to concerns about protecting their intellectual property and navigating legal challenges associated with data usage and ownership (Nofal et al., 2020). Organizations must comply with existing regulations and standards while adopting I5.0 technologies. However, as I5.0 evolves, compliance requirements may change, creating uncertainties for organizations. Navigating the evolving regulatory landscape and ensuring compliance with changing standards can be challenging, leading to hesitancy in adopting I5.0 (Srivastava, 2021). The adoption of I5.0 technologies raises ethical considerations and social implications that organizations must address. For example, job displacement due to automation can create social challenges, and the ethical use of data in I5.0 systems requires careful consideration. If organizations perceive negative social impacts, they may be hesitant to adopt I5.0 technologies, prioritizing ethical and social responsibilities (Moore & Wong, 2020).

I5.0 implementation often requires substantial upfront investments in technology infrastructure, software and training programs. These investments can be financially burdensome, particularly for organizations with limited financial resources. The high initial investment required for I5.0 adoption can act as a barrier, preventing organizations from fully embracing these technologies (Palacios-Argüello et al., 2021). Organizations may hesitate to adopt I5.0 technologies if they are uncertain about the potential return on investment and the long-term benefits. The lack of clear business cases and proven success stories may deter organizations from investing in I5.0, as they seek assurance of the economic viability and return on their investments (Palacios-Argüello et al., 2021).

An extensive literature review has been done to identify 28 barriers to I5.0 adoption in the supply chain for achieving sustainable goals (Table 1). Furthermore, two supply chain experts were asked to analyze the barriers given in Table 1 and identify barriers in the context of the Indian supply chain (Table 2). These ten barriers are explained below.

Methodology

Various researchers have used decision-making trial and evaluation laboratory (DEMATEL) approach to study cause-and-effect relationship among barriers to Industry 4.0 (I4.0) adoption (Nimawat & Gidwani, 2021), such as managing barriers to adoption of I4.0 in pharmaceutical supply chain (Agrawal, Sharma, Srivastav, & Devi, 2023). On similar ground, this paper tried to study barriers to I5.0 adoption to achieve sustainable supply chain in India using methodology adopted by these papers. Figure 1 outlines the methodology adopted for this study.

Twenty-eight barriers were identified using extensive literature review (Table 1). Furthermore, two supply chain experts out of which one person has been working on I4.0-related solutions, and its clients in manufacturing and supply chain solution providers of major player in the Indian IT industry, and other expert who is working in logistic industry were asked to evaluate these barriers and identify barriers which are relevant to I5.0 implementation for sustainable supply chain (SSC) in Indian context. A total of ten barriers were identified by SC experts presented in Table 2. A matrix of pairwise influence for these ten barriers was developed and shared with eight industry experts having experience of more than 12 years in the field of supply chain. These experts were requested to fill up this matrix to show pairwise influence between these ten barriers on the scale of 0–4, 0 – no influence, 1 – low influence, 2 – medium influence, 3 – high influence and 4 – very high influence (Agrawal et al., 2023).

Barriers for adoption of I5.0 in SCS	References
Management support/lack of active involvement of the senior managers	Dwivedi, Agrawal, Jha, Mathiyazhagan (2023) and Yadav et al., (2020)
Resistance to change and lack of digital readiness	Oksuz (2020)
Organization readiness and expectation in transformation	Dwivedi, Agrawal, Jha, Mathiyazhagan (2023)
Attitudinal transformation of consumers	
Concern for environmental protection and sustainability	Chauhan et al. (2021a, 2021b); Moktadir, Rahim, Habib, and Shah (2018). Raj et al.
Insufficient IT infrastructure and connectivity	Jing et al. (2020a, 2020b)
Lack of reliable information and technological	Kaur, Singh, and Sandhu (2020)
Lack of in-house talent and skilled workers	
Lack of standardized protocols and interoperability: Incompatibility between different systems and technologies hinders seamless integration and communication within the supply chain	Hsieh et al. (2020a)
Competency skills for collaboration among humans and machines	Adel (2022a, 2022b, 2022c)
Inadequate knowledge about disruptive technologies	Majumdar, Kumar, and Kumar (2021) and Stentoft et al. (2020)
Lack of organizational capabilities and commitment	Aslam et al. (2020) and Yadav et al. (2020)
Insufficient investment	Kumar, Jain, and Kumari (2021)
Risk in data ownership and data security	Singh et al. (2020)
Market uncertainty	Luthra and Mangla (2018)
Cybersecurity and data privacy concerns	Huang et al. (2021a, 2021b)
Difficulties in the data management system	Zheng, Yuan, and Huang (2018)
Disruptions to employment	(Frey & Osborne, 2017; Moktadir et al., 2018)
Implementing I5.0 technologies often requires significant investments in hardware, software and workforce training, making it a barrier for organizations with limited financial resources	Rame et al. (2023)
Inadequate regulatory frameworks and policies addressing the adoption of I5.0 and its impact on supply chain sustainability	Singh et al. (2020)
Lack of financial support, funding like taxcuts, short loans, etc. from investors and the Government	Karmaker, Ashraf, and Matin (2021)
Lack of skilled workforce proficient in emerging technologies	Adel (2022a, 2022b, 2022c)
Education and skills, working environment, the relationship between productivity and wages, technologies and human redundancies, optimum products, sustainability, governance and ethics	Frederico (2021); 5(3):49
Coordination and leadership support, digital infrastructure, strategic alignment and people skills and training	
Psychological issues, workers' safety, social, ethical, learning and legal and regulatory issues	
Technological to a balanced human-centric perspective	
Security is a challenge for I5.0 as it is critical to establish trust in ecosystems	

Source: Secondary data

Table 1.
Barrier to technology adoption

Table 2.
Barriers to I5.0 adoption in SC in India

Code	Barriers
B1	Implementation cost
B2	Lack of support from the Government
B3	Inadequate knowledge of disruptive technologies
B4	Lack of reliable information and technological
B5	Management support
B6	Lack of in-house talent and skilled workers
B7	Risk in data ownership and data security
B8	Lack of organizational capabilities and commitment
B9	Market uncertainty
B10	Security concern

Source: Created by authors

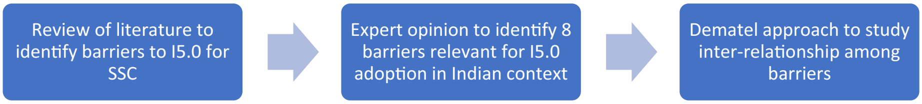


Figure 1.
Methodology

Source: Figure by authors

DEMATEL approach had been used to study interrelationship among identified ten barriers. DEMATEL is helpful in identifying interrelationship among barriers and can develop a structural framework to study barriers (Singh, Singh, & Khamba, 2021). Although there are few more modeling methods such as "interpretive structural modeling," "analytical network process," "total interpretive and structural modeling" and "graph theory and matrix approach," which helps in identifying interrelationship among barriers. However, DEMATEL approach not only helps to study interrelationship among barriers but also useful to identify effect of interrelationship of barriers (Yadav et al., 2020; Nimawat & Gidwani, 2021). DEMATEL is the widely used approach in research work done in the field of I4.0 and SC (Bhagawati, Manavalan, Jayakrishna, & Venkumar, 2019; Hossain and Thakur, 2021; Agrawal et al., 2023). DEMATEL is an appropriate method to study interrelationship among barriers to I5.0 adoption for supply chain sustainability. All steps of DEMATEL (Agrawal et al., 2023; Nimawat & Gidwani, 2021) are briefly discussed below:

(1) *Step 1:* Each industry experts were requested to fill up matrix $[b_{ij}]$ to measure the extent to which barrier B_i influences barrier B_j. We received response from eight experts n form of matrix represented by $[b_{ij}^{1}]$ $[b_{ij}^{2}]$. . .. . ..$[b_{ij}^{10}]$, which is denoted by $[b_{ij}^{\mathrm{m}}]$ in this paper, where m is number of respondents.

(2) *Step 2:* Average direct relationship matrix T (Table 3) was determined using equation (1):

$$T = 1/m \sum_{i=1}^{m} b_{ij}^{m} \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

(3) *Step 3:* Normalized direct relationship matrix (Table 4) was developed using equation (2):

$$D = \frac{T}{K} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0	2.5	3	2	4	1.5	1	2.5	2	1
B2	3	0	2	2.5	2	3.5	1.5	3	4	3.5
B3	3	1.5	0	3.5	2.5	3	3	3	1	4
B4	4	2.5	4	0	2.5	2.5	4	2.5	1	3
B5	2	1.5	3	4	0	3.5	1	2.5	3	2
B6	3	1	3	4	4	0	3	2	2	1
B7	3	3	4	1	2.5	1	0	3	3	4
B8	1	3.5	2	2.5	3	3.5	4	0	2	1
B9	3	2	1	2.5	4	2	3	2.5	0	1
B10	2	4	3	2	3	2	4	2	2	0

Source: Created by authors

Table 3. Average direct relationship matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.0000	0.0962	0.1154	0.0769	0.1538	0.0577	0.0385	0.0962	0.0769	0.0385
B2	0.1154	0.0000	0.0769	0.0962	0.0769	0.1346	0.0577	0.1154	0.1538	0.1346
B3	0.1154	0.0577	0.0000	0.1346	0.0962	0.1154	0.1154	0.1154	0.0385	0.1538
B4	0.1538	0.0962	0.1538	0.0000	0.0962	0.0962	0.1538	0.0962	0.0385	0.1154
B5	0.0769	0.0577	0.1154	0.1538	0.0000	0.1346	0.0385	0.0962	0.1154	0.0769
B6	0.1154	0.0385	0.1154	0.1538	0.1538	0.0000	0.1154	0.0769	0.0769	0.0385
B7	0.1154	0.1154	0.1538	0.0385	0.0962	0.0385	0.0000	0.1154	0.1154	0.1538
B8	0.0385	0.1346	0.0769	0.0962	0.1154	0.1346	0.1538	0.0000	0.0769	0.0385
B9	0.1154	0.0769	0.0385	0.0962	0.1538	0.0769	0.1154	0.0962	0.0000	0.0385
B10	0.0769	0.1538	0.1154	0.0769	0.1154	0.0769	0.1538	0.0769	0.0769	0.0000

Source: Created by authors

Table 4. Normalized direct relationship matrix

$$where,\ K = max \sum_{i,j=1}^{n} b_{ij}$$

(4) *Step 4:* Total relationship matrix $[T]$ was generated (Table 5) using equation (3) on matrix $[D]$ obtained above to:

$$T = D(I - D)^{-1}\ \ldots\ldots \tag{3}$$

$$where\ I\ is\ the\ identity\ matrix$$

Values of D (sum of all values in a row) and values of R (sum of all values in a column) are calculated and presented in last two columns of Table 5.

(5) *Step 5:* Further values of $D + R$ and $D - R$ are presented in Table 6. Barriers are ranked according to their values of $D + R$, which show its importance and marked as effect/cause according to their $D - R$ values in Table 6.

Table 5.
Total relationship matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	D
B1	0.0807	0.1039	0.1247	0.0831	0.1663	0.0624	0.0416	0.1039	0.0831	0.0416	0.8913
B2	0.2158	0.0208	0.1018	0.1128	0.1101	0.1471	0.0660	0.1361	0.1704	0.1429	1.2239
B3	0.2134	0.0782	0.0246	0.1510	0.1290	0.1277	0.1236	0.1359	0.0549	0.1621	1.2004
B4	0.2550	0.1207	0.1833	0.0196	0.1354	0.1109	0.1637	0.1207	0.0581	0.1252	1.2924
B5	0.1767	0.0747	0.1358	0.1674	0.0272	0.1448	0.0453	0.1131	0.1290	0.0837	1.0976
B6	0.2126	0.0589	0.1399	0.1702	0.1866	0.0123	0.1236	0.0974	0.0933	0.0466	1.1413
B7	0.2094	0.1355	0.1780	0.0546	0.1284	0.0505	0.0081	0.1355	0.1315	0.1619	1.1934
B8	0.1423	0.1483	0.0933	0.1071	0.1373	0.1428	0.1593	0.0137	0.0879	0.0439	1.0759
B9	0.1990	0.0961	0.0614	0.1115	0.1845	0.0884	0.1230	0.1153	0.0153	0.0461	1.0406
B10	0.1807	0.1712	0.1362	0.0908	0.1432	0.0873	0.1608	0.0943	0.0908	0.0069	1.1623
R	1.8857	1.0082	1.1791	1.0681	1.3478	0.9742	1.0148	1.0659	0.9143	0.8610	

Source: Created by authors

Table 6.
Degree of total influence of barriers

Barriers	R	D	$D+R$	Rank	$D-R$	Cause/effect
B1	1.8857	0.8913	2.777	1	−0.994	Effect
B2	1.0082	1.2239	2.232	5	0.216	Cause
B3	1.1791	1.2004	2.380	3	0.021	Cause
B4	1.0681	1.2924	2.361	4	0.224	Cause
B5	1.3478	1.0976	2.445	2	−0.250	Effect
B6	0.9742	1.1413	2.116	8	0.167	Cause
B7	1.0148	1.1934	2.208	6	0.179	Cause
B8	1.0659	1.0759	2.142	7	0.010	Cause
B9	0.9143	1.0406	1.955	10	0.126	Cause
B10	0.8610	1.1623	2.023	9	0.301	Cause

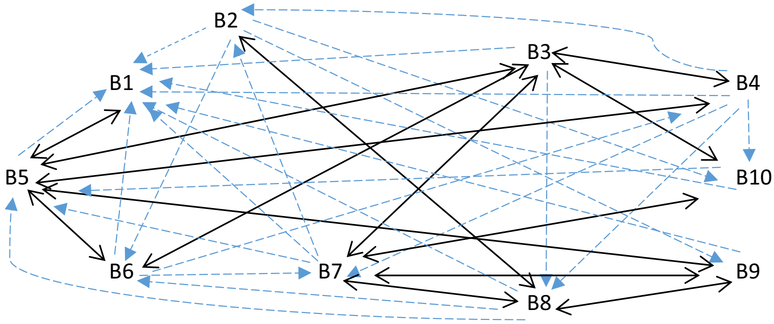
Source: Created by authors

(6) *Step 6:* A cause-and-effect diagram is generated using a scatter plot in MS Excel where the X-axis includes $D + R$ values showing the importance of the barriers and the Y-axis shows $D - R$ values reflecting the degree of influence (Figure 2).

(7) *Step 7:* The values in the total relations matrix [T], equal to or greater than the threshold value 0.1132 (average of total relationship matrix), have been identified (Table 5) with bold font and a direct graph is plotted in Figure 2 showing a causal interrelationship between ten identified barriers.

Findings and discussion

DEMATEL approach has been used to identify the interrelationship among barriers to I5.0 adoption to achieve sustainable supply chain in Indian context. Importance of selected ten barriers to I5.0 adoption has been identified in Table 6 according to the values $D+R$. B1 "implementation cost" is the most important barrier with rank 1 and score 2.777. B9 "market uncertainty" is the least important barrier with rank 10 and score 1.955. Barriers B5 "management support," B3 "inadequate knowledge about disruptive technologies" and B4 "lack of reliable information and technological" are the second, third and fourth important barriers, respectively.



Source: Figure by authors

Figure 2. Causal interrelationship among barriers

These selected ten barriers can be divided into two categories: (a) cause barriers and (b) effect barriers based on the $D - R$ value. Barriers with a positive $C - R$ value or greater than zero are known as "cause barriers" and those with negative $C - R$ values or less than zero are known as "effect barriers." According to Table 6, out of ten barriers, two barriers belong to effect group and eight barriers are cause barriers. Barriers – B2 (lack of support from Government), B3 (inadequate knowledge about disruptive technologies), B4 (lack of reliable information and technological), B6 (lack of in-house talent and skilled workers), B7 (risk in data ownership and data security), B8 (lack of organizational capabilities and commitment), B9 (market uncertainty) and B10 (Security concern) are the cause barriers, whereas barriers B1 (implementation cost) and B5 (Management support) are effect barriers. Barrier "implementation cost" (B1) is affected by all other barriers. Barrier "management support" (B5) is affected by all other barriers except by barrier (B2) "lack of support from Government."

Figure 2 shows causal interaction between barriers. The black line with two-sided arrow shows causal interaction between both barriers and dotted blue color line shows causal interaction of one barrier on another barrier:

- It has been observed that most important barrier B1 (Implementation cost) with 1st rank is influenced by all other barriers.
- Barrier B3 (inadequate knowledge about disruptive technologies) with rank 3 in terms of importance has an influence on all other seven barriers B1 (implementation cost), B4 (lack of reliable information and technological), B5 (management support), B6 (lack of in-house talent and skilled workers), B7 (risk in data ownership and data security), B8 (lack of organizational capabilities and commitment) and B10 (security concern) and can be influenced by barriers B4 (lack of reliable information and technological), B5 (management support), B6 (lack of in-house talent and skilled workers), B7 (risk in data ownership and data security) and B10 (security concern). Thus, removing barrier B3 (inadequate knowledge about disruptive technologies) can help reducing other seven barriers.
- Barrier B4 (lack of reliable information and technological), a fourth important barrier has an influence on other seven barriers B1(implementation cost), B2 (lack of support from Government), B3 (inadequate knowledge about disruptive technologies), B5 (management support), B7 (risk in data ownership and data security), B8 (lack of organizational capabilities and commitment) and B10 (security

concern) and can be influenced by barriers B3 (lack of reliable information and technological), B5 (management support) and B6 (lack of in-house talent and skilled workers). Thus, removing barrier B4 (lack of reliable information and technological) can help reducing other seven barriers.

- Barrier B7 (risk in data ownership and data security) with the rank 6 has an influence on other seven barriers B1 (implementation cost), B2 (lack of support from the Government), B3 (inadequate knowledge about disruptive technologies), B5 (management support), B8 (lack of organizational capabilities and commitment), B9 (market uncertainty), B10 (security concern) and is influenced by B3 (inadequate knowledge about disruptive technologies), B4 (lack of reliable information and technological), B6 (lack of in-house talent and skilled workers), B8 (lack of organizational capabilities and commitment), B9 (market uncertainty) and B10 (security concern).

Thus, elimination of these three cause barriers B3 (inadequate knowledge about disruptive technologies), B4 (lack of reliable information and technological) and B7 (risk in data ownership and data security) would help in removing major number of barriers to I5.0 to achieve SSC.

Conclusion

Working on solutions to remove all barriers to I5.0 adoption is a tedious task. Prioritization of these barriers for phasewise solution to these barriers and understanding their cause-and-effect relationship would help in adoption of I5.0 in SC to achieve sustainability. With this aim, this paper tries to identify importance of selected barriers to I5.0 and study the interrelationship among these barriers.

As a first step, 28 barriers to various technologies adoption were identified with the support of available literature. Thereafter, with the advice from industry experts, these identified 28 barriers were further filtered down to ten significant barriers applicable to I5.0 adoption in Indian SC. The ranking of these barriers and their interrelationship were further analyzed using the DEMATEL approach.

B1 (Implementation cost) is the most important barrier and B9 (market uncertainty) is the least important barrier in terms of significance. Two barriers, B1 (implementation cost) and B5 (management support), are the effect barriers and other eight barriers are cause barriers. The cause-and-effect diagram (Figure 2) would help supply chain practitioners to understand all barriers and their interrelationship to implement I5.0 in SC function. As discussed in the above section, elimination of three major cause barriers B3 (inadequate knowledge about disruptive technologies), B4 (lack of reliable information and technological) and B7 (risk in data ownership and data security) would help in removing majority of barriers to I5.0 adoption in SC. SC and I5.0 practitioners shall focus first on these three barriers to expedite adoption of I5.0.

There are certain drawbacks in this study. Barriers have been selected with the help of industry experts from Indian industry. These experts can be biased. Further study can discuss and identify barriers to I5.0 with large number of industry experts to get remove any probable biasness. Data has been collected from an emerging nation India. A similar work can be conducted for a developed nation, or a comparative study between emerging and developed nations can be done.

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