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ORIGINAL RESEARCH

Development of a framework for adopting Industry 4.0 integrated sustainable supply chain practices: ISM–MICMAC approach

Deepak Datta Nirmal[1] · K. Nageswara Reddy[1] · Amrik S. Sohal[2] · Minakshi Kumari[3]

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Abstract

Sustainable supply chain (SSC) practices are identified as the key solutions to deal with the rise in environmental issues, institutional pressures related to the environment, and pollution. Literature highlights that Industry 4.0 technologies enable the implementation of SSC practices and have the great potential to achieve sustainable performance by minimizing the use of resources and energy. Scholars have acknowledged the need to understand how Industry 4.0 technologies enabled SSC practices lead to gain sustained competitive advantage and sustainable performance. This research study investigates the recent trends in the literature on Industry 4.0 and SSC management areas by using a systematic literature review (SLR) and bibliometric analysis. Based on the findings of the SLR and inputs from the experts (both from academia and industry) associated with Indian manufacturing industries, an indicative list of critical success factors (CSFs) has been identified. The interrelationships between these CSFs have been analyzed using interpretive structural modeling (ISM) and MICMAC analysis. Further, using the insights gained from the SLR and ISM–MICMAC analysis and combining them with the relevant existing organizational theories namely institutional pressure (IP) theory, resource-based view (RBV), and dynamic capabilities view (DCV), this study puts forward a theoretical model and six propositions. The analysis shows that "Governmental support and policies", "Futuristic goals, vision", "Top management support, commitment, and leadership", and "Competition", are some of the important CSFs to adopt SSC practices

✉ K. Nageswara Reddy
knsr481@gmail.com

Deepak Datta Nirmal
phd20002@iimj.ac.in

Amrik S. Sohal
amrik.sohal@monash.edu

Minakshi Kumari
minakshi@mech.iitd.ac.in

1 Operations and Supply Chain, Indian Institute of Management Jammu, Jammu, Jammu and Kashmir, India

2 Department of Management, Monash Business School, Monash University, Melbourne, Australia

3 Department of Mechanical Engineering, Indian Institute of Technology Delhi, Delhi, India

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in the Industry 4.0 era. Further, it is observed that a "Skilled workforce", "Knowledge management", and "Technological capabilities" aid in the generation of innovative competencies such as the better implementation of SSC practices integrated with Industry 4.0 technologies, better supply chain integration, waste reduction, etc. These high-order innovative capabilities help organizations to achieve higher profitability, higher sustainable performance, and continuous competitive advantage in the dynamic business environment.

Keywords Critical success factors · Industry 4.0 · Digital revolution · Supply chain · ISM–MICMAC · Supply chain · Sustainability · Systematic literature review

1 Introduction

Adopting sustainable practices in business operations is no longer optional for firms. It is observed that anthropogenic emissions are the prime factors for the adverse climate effects, rise in global average surface temperature, heat waves, etc. (IPCC Sixth Assessment Report, WGI—2021,[1] WGII—2022[2]). This highlights the urgent need for immediate action by the global community to curb environmental emissions. Additionally, several factors such as increasing customers' awareness of the environment, social and regulatory pressures, environmental regulations, sudden climate changes, and competitive factors have forced organizations to incorporate sustainability in their entire supply chain processes (Dubey et al., 2017a, 2017b, 2017c; Luthra & Mangla, 2018; Yadav et al., 2020). In the current state, any discussion on a supply chain without a sustainability component is considered incomplete (Jabbour et al., 2020). Thus, incorporating sustainable practices is one of the key solutions to deal with the external pressures that organizations are currently facing.

In addition to sustainable supply chains (SSC), Industry 4.0 (also referred to as the fourth industrial revolution) has drawn great attention from researchers and practitioners. The term 'Industry 4.0' was first coined at the Hannover Fair in 2011.[3] The term originated from a project executed under the German government to promote the computerization of manufacturing (Hermann et al., 2016; Luthra & Mangla, 2018; Sung, 2018). According to Bag et al. (2018), digital transformation has become essential for maintaining a competitive advantage and achieving higher productivity. Industry 4.0 technologies mainly consist of cyber-physical systems, the internet of things, cloud computing, big data analytics, additive manufacturing, blockchain technology (BCT), etc. These technologies can effectively address the contemporary needs and objectives of a supply chain, such as high productivity, flexibility, innovativeness, optimization of the resources, use of sustainable manufacturing practices, and less waste generation (Cheng et al., 2021; El-Kassar & Singh, 2019; Mastos et al., 2020; Namdej et al., 2019; Rahman et al., 2021; Umar et al., 2021). They have also shown a positive impact on SSC performance and circular economy practices (Bag et al., 2021a; Belhadi et al., 2021; Cheng et al., 2021; Kamble et al., 2021; Raut et al., 2021). This shows that organizations need to coherently strategize the implementation of SSC practices in the Industry 4.0 era to gain a competitive advantage and achieve a world-class supply chain (Dubey et al., 2017a, 2017b, 2017c; Kumar et al., 2021a). For this purpose, policymakers and practitioners must understand that knowledge of both Industry 4.0 technologies and SSC is

[1] https://www.ipcc.ch/assessment-report/ar6/.

[2] https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FullReport.pdf.

[3] https://www.hannovermesse.de/en/.

crucial to harness their utmost potential by using their synergic effect (Kumar et al., 2021a, 2021b, 2021c, 2021d; Luthra & Mangla, 2018).

Despite the rich literature on 'SSC practices' and the 'application of Industry 4.0 technologies', it is observed that the availability of studies that jointly explore both of these areas is very limited (Jabbour et al., 2018). The literature lacks in providing the theoretical model which helps practitioners in framing their strategies for the adoption of 'SSC practices along with the supporting Industry 4.0 technologies'. It is also observed that there exists a gap in the literature in providing theory-focused research for analysis of SSC practices along with the impact of Industry 4.0 technologies. Attending to this motivation and following Alvesson and Sandberg (2011), the present study attempts to build a theoretical framework based on interpretive logic and organizational theories such as institutional pressure (IP) theory, the resource-based view (RBV), and dynamic capabilities view (DCV). The extant study also explores how IP drives the adoption of sustainable practices and Industry 4.0 tools. As per the arguments of Oliver (1997), IP theory and RBV are used to illustrate complex managerial decisions. This study analyzes how DCV leads to the development of an innovative bundle of competencies and avoids the core rigidities to achieve sustained competitive advantage (Sharma et al., 2022). Further, it explains the interrelations among these theories for developing sustainable performance and competitive advantage. Thus, the primary objectives of the present study are:

i. To identify the critical success factors (CSFs) of SSCM in the Industry 4.0 era, and
ii. To develop a theoretical model.

Based on the systematic literature review (SLR) and experts' advice, 32 critical success factors (CSFs) have been identified for the successful adoption of SSC practices in the Industry 4.0 era. Further, a theoretical model is developed that intends to resolve the confusion regarding these CSFs and their complex interrelations.

Based on the seminal work by Whetten (1989), the extant study provides answers to the following three research questions:

RQ1—What are the CSFs for the successful adoption of SSC practices in the Industry 4.0 era? RQ2—Why only 32 CSFs are analyzed that are derived from systematic literature review (SLR)? and RQ3—How are these CSFs interlinked?

To achieve the mentioned objectives, this study deploys SLR and bibliometric analysis, ISM, and MICMAC analysis, along with qualitative interviews. The first objective intends to address RQ1 and RQ2. As both "Industry 4.0 and SSC management" are emerging fields, a comprehensive systematic literature review (SLR) (Tranfield et al., 2003) and bibliometric analysis have been conducted. While selecting the CSFs, careful attention has been paid to ensure their parsimonious nature and special care has been taken to omit the overlapping CSFs. As an outcome of this approach, 32 CSFs have been identified. The second objective relates to RQ3 regarding the development of the theoretical framework. In this regard, Markman and Krause (2014) have suggested a need to use inductive approaches to develop a theory around SSCM. Previous literature reflects that various methods have been used for theory generation such as the case study approaches (Eisenhardt, 1989; Pagell & Wu, 2009), simulation studies, multi-method approaches (Chandrasekaran et al., 2016; Singhal et al., 2008), and grounded theory. In recent times, the use of interpretive structural modeling (ISM), and total interpretive structural modeling (TISM) are the preferred alternative approaches for the development of theoretical frameworks (Chen et al., 2018; Dubey et al., 2015, 2022a, 2022b). Besides the benefits, there are certain limitations associated with these approaches. The case study approach requires extensive time and cost, and due to the small sample size, its generalizability is also low (Singhal et al., 2008), the grounded theory-based model sometimes does not address the 'how' and 'why' questions (Dubey et al., 2017a, 2017b, 2017c), and for ISM there exists subjectivity due to variation in experts' opinion, and lack of explanations for the interpretations of the links (Dubey et al., 2015; Sushil, 2012). However, several studies have depicted the importance of developing a theoretical framework based on interpretive logic (Dubey et al., 2017a, 2017b, 2017c; Luo et al., 2018; Shibin et al., 2018; Thakkar et al., 2008). Keeping this in mind and based on the research onion framework by Saunders et al. (2009), this study develops a theoretical framework using the interpretivism philosophy. Broadly, there are three research philosophies namely positivism, realism, and interpretivism. The philosophy of interpretivism, which ontologically accepts the presence of multiple, socially-created, and politically-limited realities, serves as the foundation for the current work. Thus, the present study is guided by interpretivist philosophy which is further directed by the deductive and inductive research approaches based on the context of this study.

The remaining paper is organized into sections, as follows: Sect. 2 presents the SLR along with descriptive and bibliometric analysis to explore developments in Industry 4.0 technologies and SSCM. It provides the year-wise and journal-wise number of research articles, three field plot analysis, citations, and keyword analysis. In addition, it includes a summarized integrated model and insights drawn from the SLR. Section 3 describes the research methods adopted for the present study. ISM–MICMAC analysis is presented in Sect. 4. Section 5 consists of the results and discussion, theoretical contribution, and managerial implications of the study. A theoretical model and propositions have also been provided in this section. Section 6 concludes the present research work, highlights the limitations and suggests future research directions.

2 Literature review

The current work deploys the usage of the SLR method to select the most relevant research articles in the areas of Industry 4.0 technologies and SSCM. The SLR approach helps to find the current trends and topics, methods, and analysis and provides insights for future research (Narayanan et al., 2019). It is evidence-based, replicable, and scientific (Joshi et al., 2021). The SLR approach is used to identify the CSFs for the adoption of SSC practices in the Industry 4.0 era. The general steps that are followed in the present study are (i) research articles collection, (ii) analysis, (iii) classification based on research methods and application areas (iv) research paper evaluation, and (v) summarized framework. (Flores-Sigenza et al., 2021; Mardani et al., 2020; Narayanan et al., 2019; Seuring & Gold, 2012; Tseng et al., 2019a, 2019b; F. Zhang et al., 2020a, 2020b, 2020c).

2.1 Search and screening protocol

The peer-reviewed research papers published in top academic journals in the English language have been considered for the present work. The steps followed for the SLR are described below:

Step 1: Search strings (Total articles = 32,655)

As per the objective of the current study, the search strings used for systematically selecting the relevant research papers from the year 2000 to 2022 are "Industry 4.0" AND "Sustainable supply chain", "Industry 4.0" AND "Green supply chain", "Big data" AND "Sustainable supply chain", "Blockchain" AND "Sustainable supply chain", "Big data" AND "Green

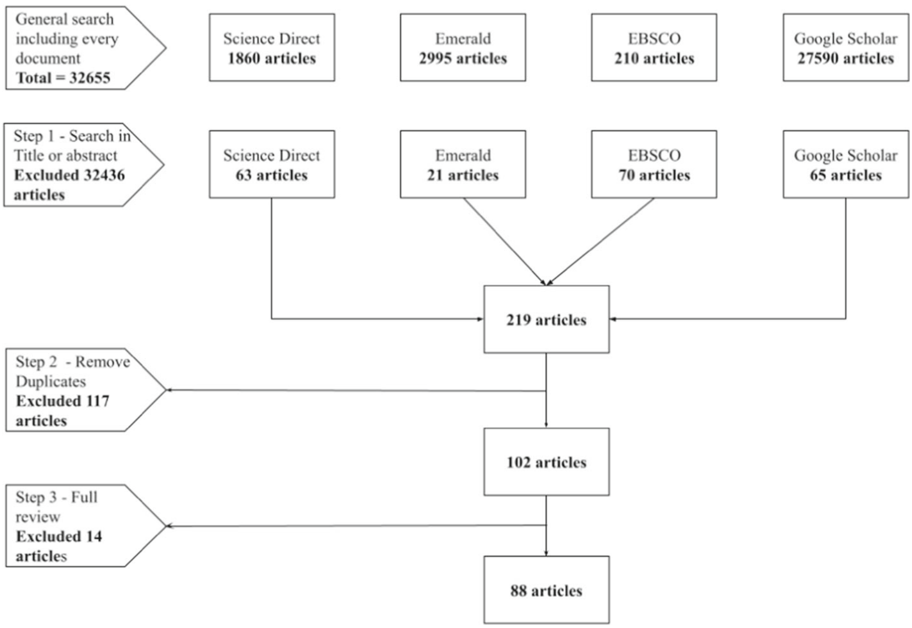

Fig. 1 Search flow diagram of SLR methodology

supply chain", "Blockchain" AND "Green supply chain". Most of the articles identified have been published since 2015. The databases primarily used for this purpose are Science Direct, EBSCO, and Emerald. The Google Scholar search tool has also been used while searching for relevant articles. Figure 1 indicates the screening process of the research articles.

Book chapters, conference proceedings, and articles published in languages other than English have not been considered in the present study. Initially, 32,655 articles have been identified using the above-mentioned search strings.

Step 2: Search limiting to title/abstract of the research articles (Total articles = 219)

This step resulted in 219 articles.

Step 3: Duplication removal (Total articles = 102)

The elimination of duplicates reduced the total count to 102 research articles.

Step 4: Relevance of the study (Total articles = 88)

Finally, after scrutiny of these 102 articles, it is decided to review and analyze the 88 research articles as per the relevance and objectives of the present study.

2.2 Analysis

Bibliometric analysis is an important method that provides reliable research information, helps to understand the trends and characteristics of publications, and aids in summarizing the published work in the related field (Caiado et al., 2017; Chalmeta & Santos-deLeón, 2020; Zhang & Zhao, 2021; Zhu et al., 2019). For performing the descriptive and bibliometric analysis, "Excel", "VOS Viewer version 1.6.10" (van Eck & Waltman, 2021), "Publish or Perish" and Biblioshiny software have been used. For Journal-wise distribution of articles,

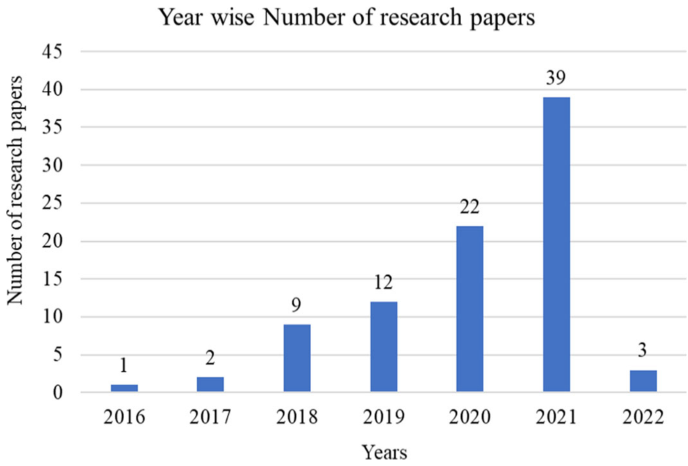

Fig. 2 Year-wise research papers

co-occurrence and keyword analysis, the top contributing authors' analysis, three field plot analysis, and citation analysis, VOS viewer and biblioshiny software have been used.

2.2.1 Year-wise research papers

Figure 2 depicts the selected papers published in previous years. Though the search covered the span between 2000 and 2022, it is found that most of the papers in the concerned domain have been published post-2015, suggesting a growing research focus in the concerned area.

2.2.2 Contribution of journals

Figure 3 shows the distribution of the papers as per the journals. The "Journal of Cleaner Production" (18 papers), "Resources, Conservation & Recycling" (10 papers), and "Technological Forecasting & Social Change" (4 papers) contributed the highest number of papers in the selected research area. These three journals comprised approximately one-third of the total count of papers (32 articles) selected for the present study.

2.2.3 Total and average number of citations

Figure 4 shows the total number of citations and the average citations for each year from 2016 to 2022. The trend depicts a steep rise in the count of citations till 2019 with the highest count of 3,057 in the year 2019, and a gradual decline in the years to follow. This decline may not be a correct representation for several reasons such as the count of citations of the papers published in the very recent years may not be truly reflected in just a couple of years, the unprecedented crisis of COVID outbreak, etc. However, this figure highlights the increasing research trend in this area from 2016 to 2019.

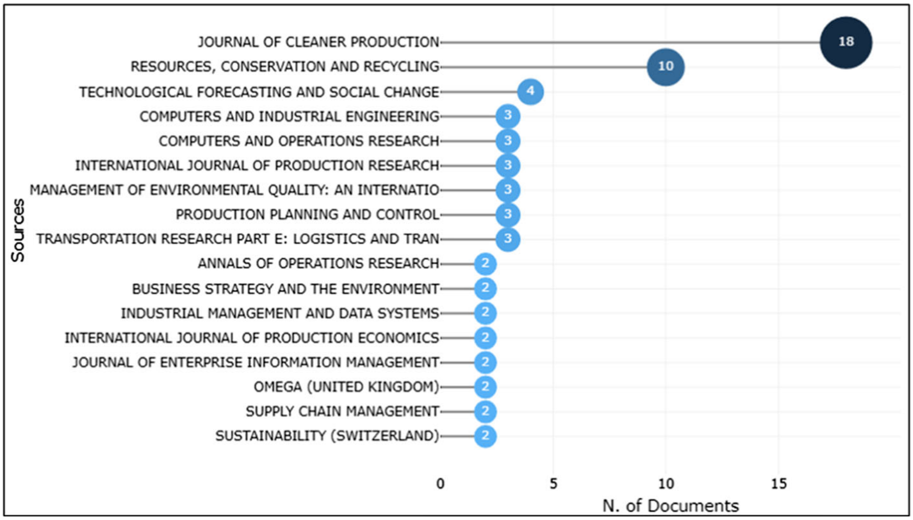

Fig. 3 Journal-wise distribution of research papers

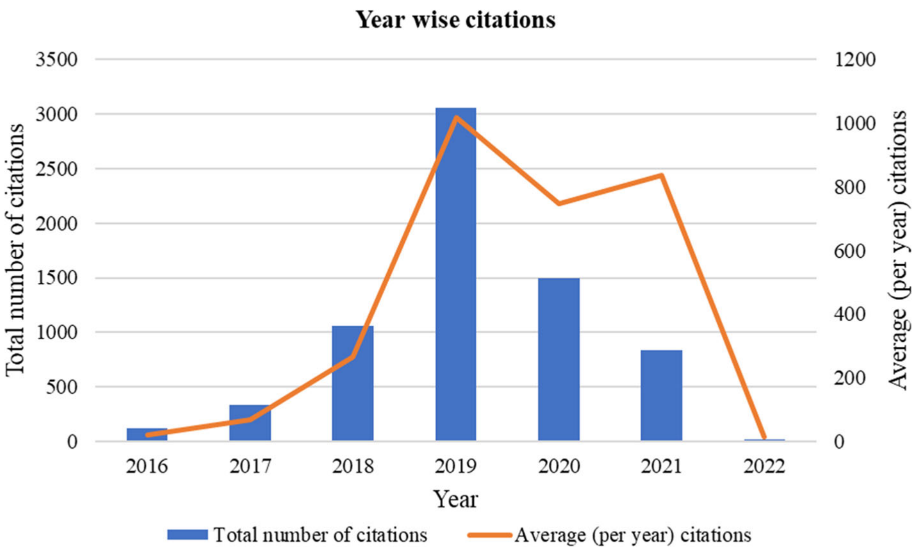

Fig. 4 Year-wise Total and average (per year) citations

2.2.4 Top authors' contribution

The top contributing authors based on the selected 88 research papers are shown in Table 1. Out of the total 289 authors, the top seven contributing authors have been shown in Table 1. Each of these authors has contributed a minimum of three papers over the period of study. Joseph Sarkis, with six articles, and Surajit Bag, with five articles, contributed the highest number of articles throughout the study period.

Table 1 Top contributing authors

Authors	Articles	Articles fractionalized
Joseph Sarkis	6	2.17
Surajit Bag	5	1.45
Ming K. Lim	4	0.95
Pan Liu	4	1.95
Amine Belhadi	3	0.58
Kumar V	3	0.70
Sachin Kumar Mangla	3	0.90
Ming-Lang Tseng	3	0.62

2.2.5 Keywords and cluster formation

A network map and clusters formed using keyword analysis help to understand the overall area and themes emerging from the literature. The keywords taken for the analysis are author-specified keywords, representing the main topic and method of the related papers. At the start, 291 keywords from 88 documents were obtained. After applying the filter of a minimum of 3 occurrences of a keyword, 24 keywords were sieved out. The same is shown in Table 2. Note that the column referring to 'color' relates to the colors used in Fig. 5.

As depicted in Table 2, "Industry 4.0", "Sustainability", "Blockchain", and "Circular economy" are the most occurring keywords. Based on these keywords and their weights (importance), a network visualization map has been developed, as shown in Fig. 5. It shows five clusters with different colors indicating overall themes, methods, or areas of research in both Industry 4.0 and the SSC fields.

Cluster 1 in Fig. 5 (colored in red) highlights methods such as SEM and bibliometric analysis used to examine sustainability, SCM, green SCM, technology, and other related topics. Items in cluster 2 (colored in green) connect Industry 4.0, "blockchain" and "big data" with a sustainable supply chain, circular economy, and green supply chain. In the future, the interrelations and impact of these concepts on each other can be studied to achieve competitive advantage and sustainable performance. Based on the occurrences of the items, it is seen that blockchain and circular economy are the most studied topics, along with Industry 4.0 and sustainability. Cluster 3 (colored in blue) consists of a triple bottom line, Sustainable supply chain management, and Supply chain performance. DEMATEL (Decision-making trial and evaluation laboratory) is also represented in cluster 3, which is the method used to analyze the interdependence among various factors like drivers, barriers, success factors, etc., of the selected area (Rane et al., 2021; Sharma et al., 2021). Cluster 4 (colored in yellow) shows that BCT, traceability, and supply chain have been studied by researchers in recent times. Finally, cluster 5 (colored in purple) identifies green innovation and big data connected with many topics related to SCM. Overall, some of the important areas emerging from the cluster analysis that can be focused on in future studies include "green supply chain and Industry 4.0 tools", "sustainability and Industry 4.0 technologies", "circular economy and 'Industry 4.0 technologies' or 'big data' or 'blockchain'", and "analysis of barriers, drivers, constructs and variables of Industry 4.0 and SSC practices". The themes emerging from the cluster analysis also overlap with the recommended future research areas by the recent literature studies (Bai et al., 2022; de Sousa Jabbour et al., 2022; Mukhuty et al., 2022; Nascimento et al., 2019; Sharma et al., 2022).

Table 2 Keywords and clusters

Sr. no.	Items (keywords)	Cluster	Color	Occurrences	Links
1	Barriers	1	Red	4	6
2	Bibliometric analysis	1	Red	4	6
3	Green supply chain management	1	Red	6	6
4	Operations management	1	Red	3	6
5	Structural equation modeling	1	Red	3	5
6	Supply chain management	1	Red	10	11
7	Sustainability	1	Red	22	17
8	Technology	1	Red	4	9
9	Big data analytics	2	Green	7	9
10	Blockchain technology	2	Green	10	12
11	Circular economy	2	Green	14	13
12	Green supply chain	2	Green	5	5
13	Industry 4.0	2	Green	27	20
14	Supply chain sustainability	2	Green	3	3
15	Sustainable supply chain	2	Green	9	8
16	Dematel	3	Blue	5	8
17	Supply chain performance	3	Blue	3	8
18	Sustainable supply chain management	3	Blue	8	10
19	Triple bottom line	3	Blue	3	6
20	Blockchain	4	Yellow	15	13
21	Supply chain	4	Yellow	9	8
22	Traceability	4	Yellow	3	3
23	Big data	5	Purple	12	9
24	Green innovation	5	Purple	3	1

2.2.6 Three-field plot analysis

A three-field plot (Sankey plot) analysis has been conducted using 'Biblioshiny' with the combination of 15 countries (Left side), 15 keywords (Middle field), and 15 titles of journals (Right side) (Sahoo, 2021). This plot shows the interaction between these fields. In Fig. 6, the size of the rectangles depicts the frequency of occurrences (Saini et al., 2022). The keyword 'Industry 4.0' is used by researchers from the mentioned top 15 countries; however, the majority of usage comes from the researchers of India, China, Greece, and the United Kingdom. Also, the keyword 'sustainability' is majorly used by researchers from the USA, India, China, the United Kingdom, and Australia. By analyzing the 'journals and keywords' interactions, it is found that the "Journal of Cleaner Production", and "Resource, Conservation, and Recycling" prefer both 'Industry 4.0', and 'circular economy'. The analysis also reveals that "Annals of Operations Research" prefers topics related to 'green or sustainable supply chain' and 'blockchain'.

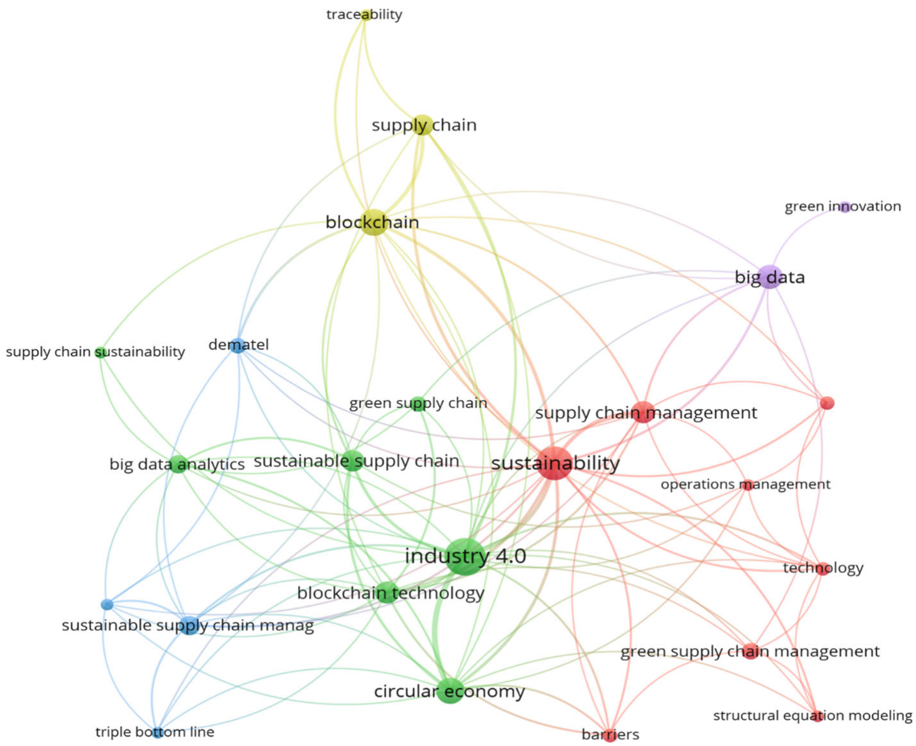

Fig. 5 Network visualization based on keywords

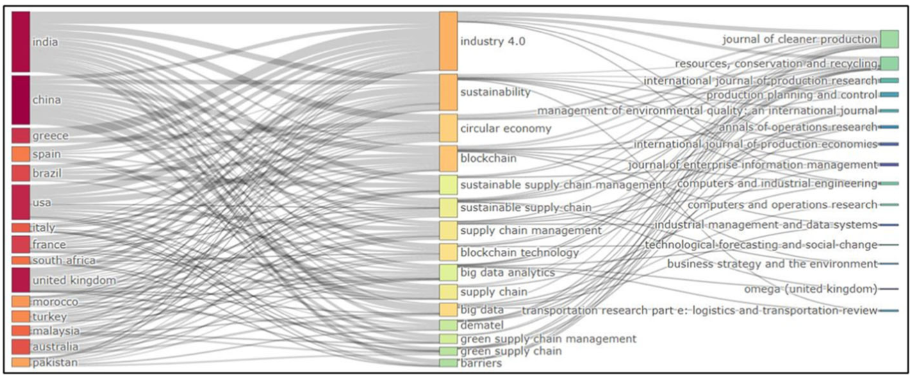

Fig. 6 Three-field plot analysis of countries, keywords, and sources

2.3 Classification of articles

Based on a critical review of previous research, the papers selected for the present study have been primarily classified into three categories. The first category includes conceptual and literature reviews along with content analysis, focused group discussions, and bibliometric analysis (see Table 3 for brief descriptions of these papers). The second category consists of studies that try to empirically investigate and test the impact of various constructs and variables by using SEM methodology. Table 4 shows the detailed analysis of these studies based on the theory applied, the industry and country in which the study was conducted, and other key variables. Figure 7 shows the summarized framework based on the research articles depicted in Table 4. This framework helps to analyze and understand the constructs, variables, and their linkages that have been empirically tested in the extant literature. This also provides an overall idea of the research questions and hypotheses that researchers have examined in the past. The third category includes research papers that try to utilize mixed methods, multi-criteria decision modeling (MCDM) methods, or other methods to analyze drivers and enablers of SSC practices, Industry 4.0 tools, and the examination of dependencies of such factors among themselves (Table 5).

2.4 Summary of the reviewed articles and identification of research gaps

In order to understand the trends and themes in literature in the areas of Industry 4.0 technologies and the SSC, the SLR approach has been adopted in the present study. From the SLR, and a descriptive and bibliometric analysis of the 88 research papers, it is evident that research in both Industry 4.0 technologies and SSC is gaining momentum. Barriers, drivers, indicators analysis, empirical investigations including interrelationships of technologies and sustainable practices, risk analysis, etc., are some of the important areas that researchers have studied. Cluster and content analysis indicate that "green supply chain" and blockchain or big data", "sustainability and Industry 4.0", "challenges for adoption of Industry 4.0 tools enabled SSC practices', etc., are some of the vital themes that are fast gaining the research interest. The summarized framework, as shown in Fig. 7, provides the overall picture of different linkages studied in the past. This framework lists the constructs and variables and thus provides directions for future research to investigate possible relationships among them.

Despite the benefits of Industry 4.0 technologies integrated SSC practices, these initiatives are relatively novel in emerging economies such as India. They are not adequately understood and hence not fully adopted by businesses (Hofmann & Rüsch, 2017; Kamble et al., 2018; Luthra & Mangla, 2018). The literature review has revealed a need for a comprehensive study to explore and examine the CSFs for adopting Industry 4.0 technologies integrated SSC practices in Indian manufacturing industries. Addressing this research gap, a further analysis of the interrelations between CSFs to adopt SSC practices in the Industry 4.0 era in the context of the Indian manufacturing sector has been taken up in the current study. Hence, the present research provides a conceptual framework (ISM model) based on the interrelations of CSFs obtained from the opinions of experts in the Indian manufacturing sector by using ISM and cross-impact matrix multiplication applied to classification (MICMAC) analysis. At length, a theoretical framework and propositions are provided for future research.

3 Research methods

To address the research gaps and achieve the mentioned objectives of the study, this section provides the overall research framework and solution methodology.

Table 3 Research papers consist of the review and conceptual studies

Sr. no.	References	Key description
1	Cetindamar et al. (2022)	This study provides three propositions that majorly explain how big data analytics capabilities (BDAC) influence SSCP and enlists the various BD capabilities. Empirical research is suggested in the same direction
2	Parmentola et al. (2022)	This review paper tries to study the impact of BCT on environmental sustainability and its positive and negative effects by using the SLR approach
3	Romero-Silva and de Leeuw (2021)	This paper used text mining analysis tools to analyze the review studies from 1956 to 2019 in OR and Management Science areas. It suggested different trends and recent study areas like big data, Industry 4.0, SSC, etc., and provided an overall analysis
4	Khanfar et al. (2021)	This review has explained the contributions of BCT to sustainable manufacturing and supply chains
5	Adams et al. (2021)	This review explains the role of food manufacturers and their role in an SSC and provides a detailed thematic analysis
6	Khan et al. (2021a, 2021b, 2021c)	This review study has systematically discussed and explained the trends in sustainable development in the context of Industry 4.0 technology
7	Inamdar et al. (2021)	Big data analytics adoption in different sectors is discussed by using SLR and bibliometric analysis
8	Zhang et al. (2020a, b, c)	Literature review and bibliometric analysis are conducted in the SSC area along with big data
9	Chalmeta and Santos-deLeón (2020)	Supply chain sustainability and Industry 4.0 and the big data area are reviewed, and six categories are identified and discussed for future research
10	Dhamija and Bag (2020)	Review and bibliometric analysis are done in the context of artificial intelligence and operations management
11	Chiappetta Jabbour et al. (2020)	A review of digitally enabled SSC is done, and seven gaps are discussed for future research
12	Cwiklicki and Wojnarowska (2020)	This study has used the SLR and content analysis to explain the relationship between Industry 4.0 and Circular economy practices
13	Ramirez-Peña et al. (2020)	Researchers tried to link SC's Lean, agile, resilience, and green paradigms with Industry 4.0 to build a highly efficient model for the shipbuilding supply chain
14	Esmaeilian et al. (2020)	Previous literature on Industry 4.0 for SSCM is studied and classified by this research study. In addition, blockchain capabilities are discussed for enhancing sustainability performance

Table 3 (continued)

Sr. no.	References	Key description
15	Song et al. (2019)	It discussed the innovative ways for sustainable development (SD). It explained the use of large-scale data for effective resource utilization, social development, and, thus, sustainable development
16	Manavalan and Jayakrishna (2019)	This review explored and discussed the IoT, ERP, Industry 4.0, and SSC in the dynamic business environment. Based on the review, it also provided the framework to assess the readiness of organizations for sustainable growth to meet Industry 4.0 requirements
17	Nascimento et al. (2019)	The current study tried to explain how circular economy practices and emerging technologies of Industry 4.0 can be merged to form new business models for recycling, reuse, etc. It has discussed various implications of this integration
18	Cole et al. (2019)	Analysis and explanation regarding the BCT in operations and SC area are provided along with the future research directions in different themes
19	Saberi et al. (2019)	BCT, smart contracts adoption in SC management, their barriers, and related classification is provided by the extant study
20	Bag et al. (2018)	This review study has contributed to the literature by analyzing the Industry 4.0 enables achieving sustainability in the SC. The role of institutional pressures and their impact on sustainability is suggested to study for future research

3.1 Overview of the research framework

In India, manufacturing is one of the high-growth sectors. To make India a global manufacturing hub, the Honorable Prime Minister of India, Mr. Narendra Modi, launched the "Make in India" program. The government of India planned to create 100 million new jobs by 2022 in the manufacturing sector (IBEF, 2021). Other government initiatives, including "Digital India", "Startup India", *"Self-reliant India", "Production linked incentives" and "Make in India 2.0" are all aimed* at growing the Indian industries and markets. When manufacturing across the globe is progressing rapidly in the era of Industry 4.0, India needs to focus on coupling various existing schemes with Industry 4.0 to develop a world-class manufacturing infrastructure (Luthra & Mangla, 2018). Thus, manufacturing industries in emerging economies must understand the underlined CSFs for adopting Industry 4.0 technologies integrated SSC practices. The preceding section (Sect. 2) presented the SLR and investigated the current trends and critical factors required to implement SSC practices in Industry 4.0 era. It is evident from the literature that these practices help industries to gain a competitive advantage and achieve sustainable organizational performance. Figure 8 shows the overall research framework, which has been proposed in two phases.

The first phase consists of the SLR approach, which is explained in detail with all the steps in Sect. 2. From the review, the CSFs have been obtained for adopting SSC practices

Table 4 Structural equation modeling-based research articles

Sr. no.	References	Industry/sector	Theory	Country of case study	Key description
1	Umar et al. (2022)	Manufacturing firms	Practice-based view (PBV)	Pakistan	The impact of Industry 4.0 on environmental and economic performance is tested for an emerging economy
2	Paul et al. (2021)	Tea	Resource-based view, Network theory	India	The BCT-driven tea supply chain model is analyzed by using PLS-SEM
3	Belhadi et al. (2021)	Multiple sectors	Practice-based View (PBV) and dynamic capability view (DCV) theories	Mediterranean basin and Southern Asia	Impact of Industry 4.0 Sustainable SC performance is studied along with other variables like Digital business transformation, Organizational ambidexterity, Circular business models
4	Edwin Cheng et al. (2021)	Manufacturing firms	Dynamic capabilities theory	Indian	Linkages between BDA capabilities, SSC performance, SSC flexibility, and CE practices are explored. It is found that there is no direct impact of BDA capabilities on SSC Performance, but an indirect impact exists. CE practices and SSC flexibility acted as significant mediating variables

Table 4 (continued)

Sr. no.	References	Industry/sector	Theory	Country of case study	Key description
5	Benzidia et al. (2021)	Hospital/healthcare	Organizational information processing theory	France	It explained how BDA AI benefits environmental performance and studied the GDLO moderation effect
6	Sislian and Jaegler (2021)	Diverse industries	Organization Information Processing Theory (OIPT)	Europe	This study has recommended the use of the BCT and ERP systems to improve supply chain strategy and corporate performance
7	Mubarik et al. (2021)	Manufacturing sector	NIL	Malaysia	The impact of BCT on GSC practices is tested with mediating role of environmental orientation. Although technological orientation does not perform well as a moderator, it is suggested not to ignore its importance
8	Khan et al., (2021a, 2021b, 2021c)	SMEs manufacturing industries	Practice-Based View (PBV) theory	China and Pakistan	This study has explained and validated the impact of BCT on GSCP to improve organizational performance
9	Kamble et al. (2021)	Automotive sector	Dynamic Capabilities View	India	This study has explained and assessed the relationship between BCT, SCI, and SSCP for Indian automotive companies

Table 4 (continued)

Sr. no.	References	Industry/sector	Theory	Country of case study	Key description
10	Raut et al. (2021)	Manufacturing firms		India	The role of big data as a mediator between SSCBP and other key factors like social, environmental, financial practices, etc., is studied
11	Bag et al., (2021a, 2021b, 2021c)	Manufacturing firms	Organization Information Processing Theory (OIPT)	South Africa	The study has shown the application of Industry 4.0 tools to improve sustainability under the circular economy mediation
12	De Giovanni and Cariola (2021)			Europe	This study has discussed the impact of process innovation strategies on the relationship between lean, GSCM, and performance
13	Lu et al. (2020)	Manufacturing firms		Pakistan	The moderating and mediating effect of corporate image and organizational innovation is studied on the relationship between the variables from the modified Carroll's pyramid and organizational performance
14	Wang et al. (2020)	Manufacturing firms	Stakeholder theory	China	Big data analytics capabilities of the firms are studied as a moderator between the CSR and GSCM

Table 4 (continued)

Sr. no.	References	Industry/sector	Theory	Country of case study	Key description
15	Bag et al. (2020)	Mine	Dynamic Capabilities Theory	South Africa	To improve SSC performance, BDA management and talent capabilities are studied by understanding their impacts on employees and innovative product developments. Stress on employee development, learning performance, and product innovation is given due to their importance in organizations
16	Singh and El-Kassar (2019)		Dynamic Capabilities Theory	The Middle East and North Africa (MENA) region and Golf-Cooperation Countries (GCC)	The relationship between corporate commitment, big data, and sustainable performance is studied. Also, green innovation, GSC Collaboration green HRM practices are studied as per the conceptual model. GHRM is studied as a moderator for some relationships
17	El-Kassar and Singh (2019)		Resource-based view theory	MENA and GCC	A complex model exploring the relationship between the drivers of green innovation practices, the impact of BDA on sustainable performance, and the moderating role of management commitment and HR Practices are studied

Table 4 (continued)

Sr. no.	References	Industry/sector	Theory	Country of case study	Key description
18	Namdej et al. (2019)	Pharmaceutical industry	Dynamic capabilities theory	Thailand	Mediating effects of green innovation and SC collaboration on the impact of big data on environmental performance are studied
19	Jeble et al. (2018)	Automobile industries	Resource-based view theory and contingency theory	India	The impact of BDPA on Social, economic, and environmental performance is studied, and the resources required to develop such BDA capabilities are thoroughly discussed

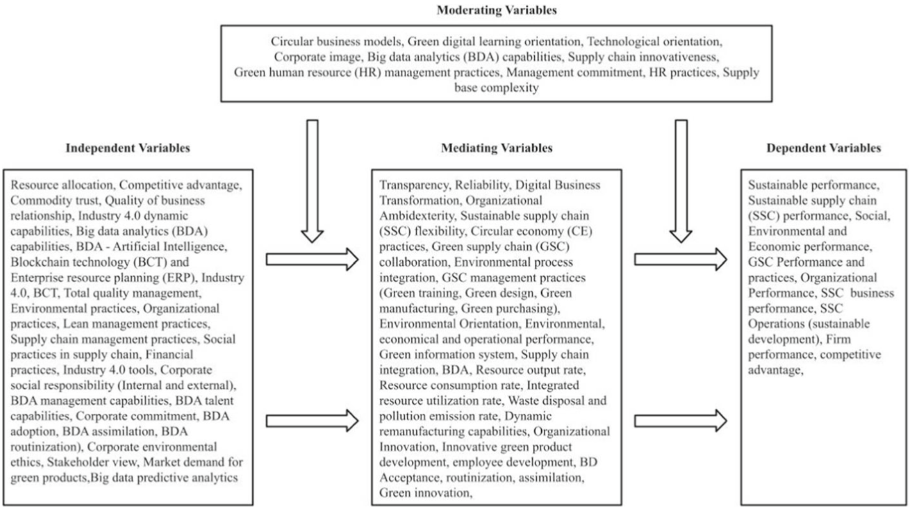

Fig. 7 A summarized framework of variables and their linkages

integrated with Industry 4.0 technologies. The list of the CSFs with detailed descriptions is provided in Sect. 4 of this paper. In phase two of this study, ISM–MICMAC analysis has been conducted based on consultation with experts from the Indian manufacturing sector and academicians. The idea of developing an overall research framework is motivated by prior research by Kannan (2018). Further, based on these analyses, six propositions and the theoretical model are provided for future research.

3.2 Solution methodology—interpretive structural modeling

ISM is an interactive learning process, initially proposed by Warfield (1974), and a well-established methodology that helps to identify and summarize relationships between elements that describe a problem or issue (Mandal & Deshmukh, 1994; Rajput & Singh, 2019). ISM can transform the unclear and feebly articulated rational models of different systems into comprehensively structured and well-defined unambiguous models (Attri et al., 2013; Jena et al., 2017; Kannan, 2018; Sage, 1977; Sushil, 2012). ISM is defined as "The process aimed at assisting the human being to understand better what he/she believes and recognize clearly what he/she does not know" (Attri et al., 2013, p. 3). Researchers have widely used the ISM methodology in various applications due to its high potential to transform a complex problem into easy, clear, and uncomplicated models with improved insights (Kannan, 2018; sage, 1977; Talapatra et al., 2022).

In the present study, the ISM methodology has been used to frame the interrelationships among the CSFs that are critical to the industry's adoption of SSC practices in the Industry 4.0 era. Initially, all the important factors from past literature have been listed. Out of these factors, it is found that some of them are common and meaning-wise similar in nature. By eliminating these meaning-wise similar and common CSFs, 39 CSFs have been obtained. Later, based on the consultation with two industry experts (from the Indian manufacturing sector) and two academicians who have profound knowledge of both Industry 4.0 technologies and sustainability, some CSFs have been further merged and/or removed, and at last,

Table 5 Research papers that include varied research methods, and key description

Sr. no.	References	Methods used	Key description
1	Kumar et al. (2021d)	Delphi method, ISM, ANP	Barriers of CE and Industry 4.0 adoption in the agriculture supply chain are analyzed
2	Tsai et al. (2021)	Fuzzy Delphi method, Entropy weight method Fuzzy decision-making trial and evaluation laboratory	Indicators are identified for future research
3	Rane et al. (2021)	DEMATEL and exploratory analysis	Identification of success factors for stakeholders' involvement in GSC is studied with the DEMATEL method
4	Kusi-Sarpong et al. (2021)	Best Worst Method and modified Delphi approach	Identification of risks and strategies to overcome them for implementing big data analytics in SSC is studied
5	Liu (2021)	Game theory	Cost-sharing models and pricing rules are studied using game theory for one green manufacturer and retailer
6	Gunduz et al. (2021)	Best–Worst Method (BWM) and Quality Function Deployment (QFD	Maturity level for digital transformation by matching the SCM functions with smart and sustainable tools is assessed using the QFD and BWM methods
7	Kumar et al., (2021c)	ELECTRE, AHP	Barrier's analysis is done for the adoption of Industry 4.0 and CE practices
8	Tseng et al. (2021)	Fuzzy Delphi method (FDM), entropy weight method (EWM), and fuzzy decision-making trial and evaluation laboratory (FDEMATEL)	A bibliometric data-driven study is done to find the hidden indicators in SSC finance
9	Mastos et al. (2021)	Case study research	It showed how circular economy and Industry 4.0 could be practically applied in practice and provided empirical evidence for the same

Table 5 (continued)

Sr. no.	References	Methods used	Key description
10	Sharma et al. (2021)	Mixed method (Exploratory study + AHP, DEMATEL)	This study has used a mixed-method for analyzing the drivers and barriers to the adoption of Industry 4.0 in sustainability for MMSC of Indian manufacturing firms
11	Diniz et al. (2021)	Semi-structured interview	Blockchain-based application is discussed to improve the GHG protocol program and thus to transparently track the product-related history
12	Kazancoglu et al. (2021)	Fuzzy AHP and TODIM	Industry 4.0-based responses are proposed to overcome the risks while transitioning from a linear to a circular economy model
13	Peide Liu et al. (2021)	BWM	Barriers and their rankings in the context of BCT-enabled SSC are discussed
14	Bai et al. (2021)	Nash Equilibrium and game theory	Trust management and green data supply chain are proposed in the agriculture system using blockchain
15	Kouhizadeh et al. (2021)	DEMATEL	Barriers to blockchain adoption in the context of SSCM are discussed from TOE (technological, organizational, and environmental) and Force field theories
16	Saurabh and Dey (2021)	Conjoint Analysis	Drivers of the blockchain adoption in the agri-food supply chain (Grape wine supply chain) are discussed
17	Kshetri (2021)	Case studies	The importance of blockchain characteristics in sustainability is discussed in detail. Also, the use of the blockchain in bridging the enforcement gap and CSR-related regulations is suggested for future research

Table 5 (continued)

Sr. no.	References	Methods used	Key description
18	Caldarelli et al. (2021)	Semi-structured interview	Barriers and solutions regarding adopting BCT for the fashion supply chain in the context of sustainability are discussed
19	Boutkhoum et al. (2021)	IFAHP and DEMATEL	Evaluation of barriers for implementing BCT in SSCM is considered, and TOE and service sector perspectives are used for analysis
20	Govindan and Gholizadeh (2021)	Cross entropy algorithm is used in scenario-based Robust optimization model	A resilient reverse logistics network for end-of-life vehicles is discussed in detail
21	Agrawal et al. (2021)	Conceptual + Case study	Blockchain-based traceability framework is developed for tracing the products in the textile and clothing industry. Also, a discussion regarding the SSCM is provided
22	Kumar et al. (2021a, b, c)	Fuzzy DEMATEL	CSFs are analyzed in the context of integrating the Circular supply chain and Industry 4.0 to achieve sustainability
23	Bag et al. (2021a, b, c)	Fuzzy DEMATEL	Barriers and their relations to BCT adoption in the green supply chain are discussed
24	Ghosh et al. (2020)	Game theory	Strategic decisions based on market characteristics are discussed in the context of Industry 4.0 and environmental factors

32 CSFs have been finalized for the current study. For example, CSFs like “Government policies”, “Government regulations’, and “Government incentives” have been merged into a CSF named “Government support and policies”. Some CSFs like “Use of advanced predictive maintenance system”, “Supplier commitment for sustainability adoption” and “capability to adopt new business models” have been dropped due to high similarity with other CSFs or due to lack of contextual relevance. Further, some CSFs like “Understanding of Industry 4.0”, “Knowledge of environmental impact”, and “Awareness of Industry 4.0”, have been combined as “Knowledge for both SSC practices and Industry 4.0”. In this manner, based on the experts’ advice and prior literature, aggregation has been done. The list and the detailed

Table 5 (continued)

Sr. no.	References	Methods used	Key description
25	Ma et al. (2020)	Optimized model for examining the Coordination mechanisms	This study explored the coordination mechanism under cap-and-trade regulation for three echelons cold supply chain
26	Yadav et al. (2020)	BWM, ELECTRE	Framework regarding the SSCM challenges and their solution measures from the angle of circular economy and Industry 4.0 is provided
27	Pan Liu et al. (2020)	Game theory	A suitable supply chain structure is proposed in the fusion environment of blockchain and big data technologies for the green agri-food supply chain
28	Mastos et al. (2020)	Case study and Conceptual	The impact of the IoT solution on SSCM is studied by using the case study from scrap metal producer
29	Dev et al. (2020)	Simulation and Taguchi experimental design	Operational excellence in the context of integrating Industry 4.0 and circular economy is proposed by the present study for a sustainable reverse logistics system
30	Rane and Thakker (2020)	TISM	Blockchain and IoT-based integrated architecture is suggested to overcome the challenges faced by industries for sustainable green procurement
31	van Lopik et al. (2020)	Comparison study (Experiment study)	This study has discussed the human courier in the context of the Industry 4.0 supply chain. It has focused on the safety of the user and the accuracy of the performance of the task
32	Yadav and Singh (2020)	PCA, Fuzzy DEMATEL	This study discussed the use of BCT for building efficient SSCM. The important blockchain variables are identified and analyzed using the PCA and fuzzy DEMATEL

Table 5 (continued)

Sr. no.	References	Methods used	Key description
33	Zhang et al., (2020a, b, c)	Blockchain-based Life Cycle Analysis	This study has provided the BCT-based LCA framework, helped to overcome the large data tracking challenge, and tried to improve the environmental performance of SC
34	Shoaib et al. (2020)	Survey method and AHP	Blockchain-based SC success factors are identified and prioritized in this study
35	Bai and Sarkis (2020)	Hesitant fuzzy set and regret theory	The appraisal model and BCT-specific selection and evaluation method is discussed based on SC transparency and technical attributes. GDM is used for the same, and the psychological characteristics of the decision-makers are also focused on while developing the measurement system for selecting specific technology
36	Tseng et al. (2019a, b)	FSM (Fuzzy synthetic method) and DEMATEL	Identifying the performance factors of SSCM for the textile industry and analyzing their interrelationships using big data are major contributions of this study. Also, it discussed the use of big data in enhancing SSC performance
37	Choi and Luo (2019)	Theoretical study and analytical model (Based on newsvendor problems' SC formulation)	This study has used theoretical models to discuss the effect of data quality on the SSCM of the fashion industry. Further, it also explored the use of BCT for social welfare development, but it was found to decrease profitability. Thus, government sponsorship and environment taxation waiver schemes were suggested for a win–win situation

Table 5 (continued)

Sr. no.	References	Methods used	Key description
38	Martín-Gómez et al. (2019)	Holonic framework and Ecological Network Analysis (ENA)	It described the enablers like circular economy, digital technologies, Industry 4.0, and holonic paradigm and provided the framework for achieving sustainability and managing the complexity of SC
39	Nayak and Dhaigude (2019)	Literature review, ISM, MICMAC	A conceptual model for SSCM using BCT is provided for SMEs. CSFs for SSCM were identified using BT in SMEs and further analyzed by ISM
40	Dallasega and Sarkis (2018)	Proximity analysis	Proximity analysis is used to understand the complexity in various aspects of the supply chain, especially in green SC and new technologies like Industry 4.0
41	Gružauskas et al. (2018)	Logistics Network Model	It explained the technology-based strategy, which can help to effectively optimize the tradeoff between costs and environmental impact and improve sustainability in SC. It discussed the organizational dimension, information capabilities, and Industry 4.0 in SC
42	Luthra and Mangla (2018)	EFA, AHP	Challenges to adopt Industry 4.0 initiatives for SSCM are analyzed in detail for Indian manufacturing industries
43	Kaur and Singh (2018)	MINLP and heuristic method	An environmentally sustainable procurement and logistics model using big data is suggested

description of these 32 CSFs are given in Sect. 4 of the paper. Further, to form contextual relations among these CSFs, feedback from 11 experts (nine from industry and two from academia), has been used. The experts have been identified using a snowball sampling method. The industry experts included managers and other top executives from different manufacturing subsectors, all having worked in the manufacturing domain for more than five years. Initially, four experts have been selected based on their availability and suitability, and

Table 5 (continued)

Sr. no.	References	Methods used	Key description
44	Jiao et al. (2018)	Distributed robust optimization model (DRO) and Adaptive robust model (ARO)	CLSC design problem under uncertainties is studied, and data-driven approaches are suggested to design the optimization model
45	Doolun et al. (2018)	Data-driven hybrid evolutionary analytical approach by integrating Non -dominated Sorting Genetic Algorithm-II (NSGA-II)	Multi-objective model for the location-allocation problem is discussed. For it, a data-driven hybrid evolutionary analytical approach is used
46	Badiezadeh et al. (2018)	Double frontier Network Data envelopment analysis	Discussion regarding the assessment of SSCM performance under the big data context has been provided by this study. A new Network DEA model is given for the same
47	Pan Liu and Yi (2017)	Game situations were proposed based on the Stackelberg game and Nash Equilibrium game theories	These papers discussed the different pricing policies using game theory (Stackelberg game and Nash Equilibrium game theories) in GSCM. It has discussed targeted advertising and the product's green degree for a two-stage GSC system under a big data environment
48	Zhao et al. (2017)	Multi-objective optimization model	The multi-objective optimization model is discussed by considering the risks, carbon emissions, and economic costs at different levels
49	Bai et al. (2016)	Rough set-theoretic and Fuzzy clustering means (FCM) approaches	Integrated use of rough set theory and clustering method is shown for understanding the investment in GSC

later, based on the references of these experts, another seven experts have been contacted. Semi-structured interviews have been conducted with each expert to understand their opinion about the relationships among CSFs. Questioning with the experts has been on understanding which CSF leads to achieving another CSF and whether or not the CSFs are related to each other. In this regard, the matrix questionnaire has been formed to understand the relationship among the CSFs. The opinion of the experts has been marked in the form of either of the

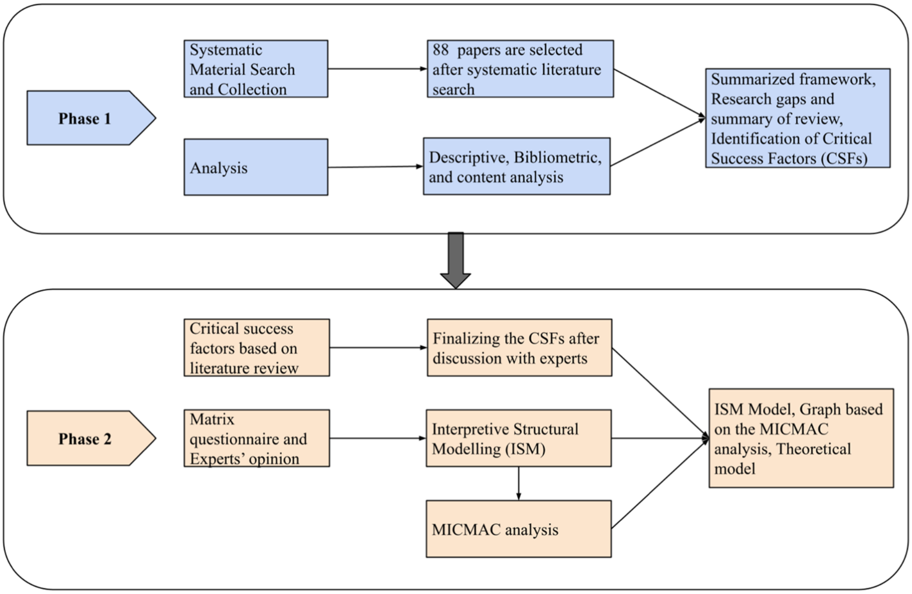

Fig. 8 Overall research framework

four symbols "V", "A", "X", and "O" as given in Sect. 4.2. This approach has been used to fill each of the questionnaires. Some of the experts have not only provided their opinions in terms of symbols "V", "A", "X", and "O" but also given the logic behind their opinions. These logics have also been noted down and further rechecked with the experts. For example, one of the experts (with work experience of more than 10 years in manufacturing industries) opined that *"green design and other practices show intention…I need to design products so that they can be recycled later. Suppose you are using plastic pens. If you do not design them properly, you cannot recycle them well."* With such logic of eco-design strategy where the product is designed with the view of recycling, he/she suggested that green practices will help to achieve the 6Rs (reduce, reuse, recycle, refuse, repair, rethink). Another expert (from the automobile sector), while commenting on the relationship between "CSR" and "green practices," expressed that *"good CSR practices help to achieve green practices… These practices also motivate employees…. Every employee feels that he is doing something for society along with the job. This also helps companies because motivated employees do new things by adding creativity and innovation…"* With this logic, it is interesting to investigate how CSR may lead to green innovation and how it also impacts employee-level outcomes. One of the experts stated that *"government support and policies are the biggest motivators for the green practices…."*. Other experts have suggested that integrated technological platforms will enhance flexibility in operations and increase collaboration among SC members. The importance of a data-driven decision-making culture is also stressed for efficient and productive business operations. On an average, completing a questionnaire with an expert took 2 h and 40 min. For some experts, multiple rounds of discussion have been conducted. Finally, the consensus has been reached based on the rule of the majority. The discussion with experts helped to form the structural self-interaction matrix (SSIM) as given in Sect. 4.2. In this way, the approach of using SLR and bibliometric analysis, semi-structured interviews to form the SSIM in connection with ISM–MICMAC analysis, and multiple organizational theories for the development of the theoretical model adds thoroughness to the study by permitting triangulation. It helps to avoid the intrinsic biases that usually arise with the usage of a single method, single data source, and single theory-based studies (Denzin, 1970; Iyengar et al., 2017; Jack & Raturi, 2006).

The relationships where ties occurred between the opinions have been revisited and further discussed with the experts. The steps undertaken in the ISM methodology are as follows (Dube & Gawande, 2016; Kannan et al., 2009; Narayanan et al., 2019): i) Identification of the variables (CSFs). ii) Identify the contextual relationship between the variables and the construction of the structural self-interaction matrix (SSIM). The formation of the SSIM is based on the pair-wise comparison of the variables of the system under consideration; the development of the initial reachability matrix from the SSIM. This matrix is then checked for the transitivity rule (an assumption made in the ISM) to form the final reachability matrix. The transitive relationship means that if variable A is related to variable B and variable B is related to variable C, then variable A is necessarily related to variable C. iii) Partitioning of the reachability matrix into different hierarchical levels. iv) A directed graph (digraph) is drawn using the serial number of CSFs. Due to the presence of a transitive relationship among the CSFs, the digraph becomes complex to interpret. Hence, the digraph is simplified by eliminating the transitive relationship. v) The ISM model development—The ISM model is developed from a digraph by replacing the serial number of CSF nodes with the CSF statements. These steps of the ISM model are shown in Fig. 9.

3.3 MICMAC analysis

MICMAC is an abbreviated form of Matrice d'Impacts croises-multiplication appliqúe an classment that is generally known as cross-impact matrix multiplication applied to classification (Attri et al., 2013; Duperrin & Godet, 1973; Mor et al., 2018). MICMAC aims to analyze the driving and dependence power of the selected CSFs (Kannan, 2018; Mandal & Deshmukh, 1994). The driving and dependence power of each CSF is calculated by using the final reachability matrix. Based on these driving and dependence powers, CSFs are further clustered as: autonomous, dependent, linkage, and independent. A graph is made by using these powers, as discussed next.

4 ISM-MICMAC analysis

ISM is used to determine the interrelationships between the CSFs that are essential to adopt Industry 4.0 integrated SSC practices. The steps involved in the formation of the ISM model are given below.

4.1 Identification of CSFs

The list of all the CSFs with their detailed description and sources is shown in Table 6. This study tries to include a comprehensive list of the CSFs to provide a simplified relationship among them through the ISM model.

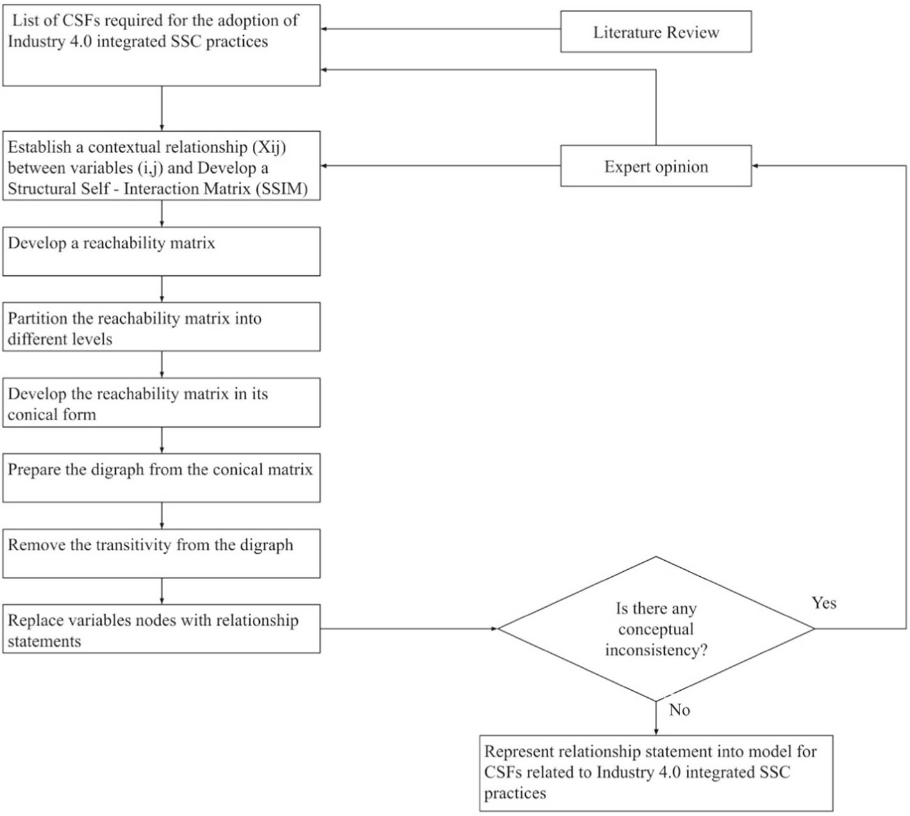

Fig. 9 Flow diagram for constructing the ISM model. [Source: Adapted from Kannan et al., 2009)]

4.2 Development of SSIM

The SSIM has been constructed based on the contextual relationship among the identified CSFs. Different types of structures, like priority structure, influence structure, and categorization of ideas, are used to analyze the CSFs (Kannan, 2018; Warfield, 1974). The present work has used the contextual relationship of type "leads to", which means that one CSF leads to another CSF. To develop the contextual relationship among the CSFs, several discussion rounds have been conducted with the selected experts. The following four symbols denote the direction of relationships among the CSFs (*i* and *j*). The letter V depicts the relationship where CSF *i* will lead to achieving CSF *j* but the reciprocal is not true. The letter A denotes the relationship where CSF *j* will lead to achieving CSF *i* but the reverse case is not correct. Thus, A and V are opposite to each other. The letter X denotes the relationship where CSF *i* and *j* will lead to achieving each other. Similarly, the letter O denotes the relationship where CSF *i* and *j* are not related to each other. Based on the contextual relationship among the CSFs, SSIM has been constructed. Table 7 shows the SSIM that has been developed based on the experts' opinions.

The below description illustrates the use of symbols V, A, X, and O, as shown in Table 7.

Table 6 CSFs for the adoption of Industry 4.0 and SSC practices

Sr. no.	CSFs	Description	References
1	Green practices (green product design, packaging, etc.) and regulations (ISO 14000)	Existing green practices help in adopting sustainable practices. Certifications inspire organizations to quality improvement and perform environment-friendly processes	Kannan (2018), Yadav et al. (2020), Sharma et al. (2021), Gandhi et al. (2016), Raut et al. (2017)
2	Rewards and incentives for greener activities	Rewards for implementing greener activities in firms can motivate members of the organization to think and adapt for sustainability	Yadav et al. (2020)
3	Promoting green innovation practices	Green process and product innovation lead to the enhancement of sustainable organizational performance. Such innovation practices will be driven by market demand, commitment from top management towards the environment, etc. Thus, innovative practices will support the adoption of both Industry 4.0 and sustainable practices	Kannan (2018), S. Kumar et al., (2021d)
4	Financial resources and investments	It is crucial to understand the vital role of investment in developing various industry capabilities to execute integrated Industry 4.0 and SSC practices effectively	Kumar et al., (2021d), Bag et al. (2020), Luthra and Mangla (2018), Raut et al. (2017)
5	Cost reduction	Due to the adoption of different practices like reuse, recycle, remanufacturing, and other sustainable practices enabled by emerging technologies, there occurs a reduction in cost for manufacturing of components, procurement of materials, time needed for manufacturing, waste disposal, etc	Raut et al. (2017)

Table 6 (continued)

Sr. no.	CSFs	Description	References
6	Understanding and predicting economic and social issues in SC	Understanding economic and social issues and their realization could lead to the effective implementation of sustainable practices	Kannan (2018), Sharma et al. (2021), Kumar et al., (2021c)
7	Focus on safety practices and safety standards	Existing standards for safety and execution of safety practices lead to a reduction in accidents and an enhancement in social performance	Yadav et al. (2020), Kannan (2018), Kumar et al., (2021c), Raut et al. (2017)
8	Encouragement of ethical and sustainable behaviors among SC partners	Ethical and sustainable behaviors lead to the enhancement in the sustainable performance of organizations. It may help to strengthen employee commitment and thus for the adoption of sustainable practices among stakeholders	Chiappetta Jabbour et al. (2020), Kumar et al., (2021c)
9	Customer awareness and involvement	Consumers' awareness of their demand for sustainable products and their involvement are some factors driving sustainable practices	Nayak and Dhaigude (2019), Gandhi et al. (2016), Raut et al. (2017)
10	Knowledge for both SSC practices and Industry 4.0	Knowledge and awareness of SSC practices and Industry 4.0 are required among the customers, suppliers, employees, and other stakeholders for their successful implementation	Luthra and Mangla (2018), Kumar et al., (2021a, b, c, d), Sharma et al. (2021)
11	Efficient knowledge management system	An effective knowledge management system helps to build employee creativity, innovation, and knowledge creation and also helps to ease sharing of knowledge among various employees. Thus, such a system boosts sustainability by integrating Industry 4.0 and SSC practices	Kumar et al., (2021a, b, c, d)

Table 6 (continued)

Sr. no.	CSFs	Description	References
12	Governmental support and policies	Government support and policies in terms of financial terms (funding), legislations regarding cyber security, environment-related other factors like subsidies, tax benefits for environmentally good performing industries, motivation for digitalization, and push for small innovative startups, etc. are important for the adoption of both Industry 4.0 and SSC practices collectively	Boutkhoum et al. (2021), Bag et al. (2018), Nayak and Dhaigude (2019), Luthra and Mangla (2018), Caldarelli et al. (2021), Kumar et al., (2021c)
13	Third-party audits	Weaknesses in firms for changing themselves to smart factories, different security issues, cycler threats, crisis management strategies, IT policies, etc., are some of the very important issues that firms can handle by using third-party audits. These audits will provide security, sustainability, and safety for networks of supply chains	Bag et al. (2018)
14	Corporate social responsibility	Firms performing CSR activities tend to experience low pressure from various stakeholders. Also, these firms can effectively implement green supply chain practices in their firms. Employee creativity, trust, commitment toward the organization, and other factors are influenced by CSR	Wang et al. (2020), Sharma et al. (2021), Raut et al. (2017)

The contextual relationship between CSF 17 and CSF 32 is denoted by “V” which means that “Top Management support, commitment, and leadership” leads to achieving the “Adoption of 6 R’s (reduce, reuse, recycle, refuse, repair, rethink)”. The contextual relationship between CSF 7 and CSF 26 is given by “A” which means “High-quality infrastructure and internet connectivity (CSF 26)” and leads to achieving “Focus on safety practices and safety standards (CSF 7)”. Similarly, the relationship between CSF 27 and CSF 28 is shown by “X” which means “IT security and data sharing protocols (CSF 27)” and “Ensuring Data quality and Data security (CSF 28)” lead to each other. The contextual relationship between CSF 12 and CSF 24 is denoted by “O” which means “Governmental support and policies (CSF 12)”

Table 6 (continued)

Sr. no.	CSFs	Description	References
15	Corporate governance	To accommodate the competition and perform well in the fourth industrial revolution, the corporate needs to change their strategies, laws, and policies that perfectly fit for Industry 4.0 adoption. Thus, they should form a new framework for value creation, and new strategies for developing a digitally-driven ecosystem	Bag et al. (2018)
16	Effective Change management	Firms, when planning to adopt Industry 4.0 and new technologies along with sustainable practices, then change in the organizational structure, new policies, and modern strategies come into play. Thus, there is a need to properly handle the resistance to change from the employees and their attitudes toward this new structure	Kumar et al., (2021a, b, c, d), Bag et al. (2018), Kumar et al., (2021c)
17	Top Management support, commitment, and leadership	Decisions and approvals regarding investment into new technologies, vision for sustainable practices and automation, high-quality standards, future strategies, etc., can be achieved by commitment and support from the top management. Top management is the apex body consisting of a board of directors who formulate a vision and the organization's mission. In addition to it, leadership style also matters in implementing various practices	Nayak and Dhaigude (2019), Luthra and Mangla (2018), Bag et al. (2018), Kumar et al., (2021a, b, c), Boutkhoum et al. (2021), Sharma et al. (2021)

and "Coordination and collaboration among members of the supply chain (CSF 24)" are not related.

Table 6 (continued)

Sr. no.	CSFs	Description	References
18	Skilled workforce	Focus on the human capital and availability of highly skilled employees is a very important prerequisite for the successful implementation of Industry 4.0-enabled sustainable practices	Bag et al. (2018), Kumar et al., (2021c), Kumar et al., (2021d)
19	Training and development programs	Adequate training can provide and develop new competencies and skills among employees to adopt new changes in the organization. A new mindset will be generated in the employees to think about integrated Industry 4.0-enabled SSC practices	Sharma et al. (2021), Kannan (2018), Kumar et al., (2021d), Gandhi et al. (2016)
20	Futuristic goals, vision	Short-term management goals are the barriers to the effective implementation of integrated Industry 4.0 and SSC practices. Thus, management should think about long-term goals, digital transformation-oriented vision, and execution accordingly	Kumar et al., (2021c), Yadav et al. (2020), Sharma et al. (2021)
21	Horizontal integration	It is the business strategy in which any particular firm acquires or merges with other firms in the same field or same value chain for various reasons like expanding business in new markets, diversifying products, growth, etc. It helps for Industry 4.0 adoption for sustainability	Bag et al. (2018)
22	Vertical Integration	Collaboration and coordination with suppliers and consumers in vertical integration help for sustainable practices. In addition, vertical integration by monitoring or controlling subsidiaries helps with the adoption of Industry 4.0	Bag et al. (2018)

Table 6 (continued)

Sr. no.	CSFs	Description	References
23	Competition	The firms which are in the same set of categories or fields and practicing either Industry 4.0 or sustainable practices or both push other firms to adopt Industry 4.0-enabled sustainable practices	Kumar et al., (2021d), Gandhi et al. (2016), Raut et al. (2017)
24	Coordination and collaboration among members of the supply chain	For adopting Industry 4.0 and sustainability practices and for understanding the organization's policies, coordination and collaboration among all the members play a crucial role. In addition, this factor is very important for effectively synchronizing software, hardware, and technologies among suppliers and respective organizations	Kumar et al., (2021a, b, c, Chiappetta Jabbour et al. (2020), Sharma et al. (2021), Gandhi et al. (2016), Raut et al. (2017)
25	Integration of technology platforms	For effective implementation of SSC practices enabled with Industry 4.0 tools and for achieving high productivity and well communication, the integration of different technology platforms is crucial. Such integrated technology platforms will act as a solution for the majority of industries which are facing difficulties in developing a flexible interface for the integration of heterogeneous components in the network	Luthra and Mangla (2018), Kumar et al., (2021a, b, c), Kamble et al. (2018)
26	High-quality infrastructure and internet connectivity	Changing or upgrading the conventional infrastructure according to modern requirements is necessary. In addition, poor internet connectivity will act as a barrier to adopting Industry 4.0 tools in firms	Kumar et al., (2021c), Luthra and Mangla (2018), Nayak and Dhaigude (2019), Sharma et al. (2021), S. Kumar et al., (2021d)

Table 6 (continued)

Sr. no.	CSFs	Description	References
27	IT security and data-sharing protocols	Industrial control systems need good security as it continuously interacts with smart components. Good IT governance in supply chain networks will ensure the adoption of Industry 4.0 and sustainability effectively. The security of systems should be checked by using different security systems to avoid any data or information leak in the initial phase of implementing new tools. Further, different protocols related to data sharing or data transfer between firms (locally or globally) should be considered	Bag et al. (2018), Boutkhoum et al. (2021), Luthra and Mangla (2018), Yadav et al. (2020)
28	Ensuring Data quality and Data security	The generation of big data due to the interconnectedness of different machines, sensors, and devices needs high data quality. Good data quality leads to the effective implementation of Industry 4.0 and innovative practices by managers and practitioners. In addition, Industry 4.0 not only generates but also uses the data to achieve organizational efficiency. It is thus crucial to protect the data for firms to adopt Industry 4.0-enabled sustainable practices	Luthra and Mangla (2018), Yadav et al. (2020)
29	Data-driven decision-making culture	It is beneficial for any organization if decision-making is done based on the data and not on only the instincts or intuitions of top executives. If a firm has data-driven decision-making culture, then employees in the firm make decisions based on the insights from data	Gupta and George (2016), Dubey et al., (2019a, b)

Table 6 (continued)

Sr. no.	CSFs	Description	References
30	Lean management practices	Lean management processes can help to reduce waste by using various processes like JIT (just in time), 5 S, cellular manufacturing, automation, etc. New technology and tools can help lean practices, or existing lean practices can also help to adopt integrated Industry 4.0 and SSC practices	Sharma et al. (2021), Kumar et al., (2021d)
31	Use of quality improvement techniques	Utilization of various quality improvement techniques like quality circles, use of digital dashboards charts, etc., help to remove non-value-adding activities and eventually leads to continuous performance	Kannan (2018), Yadav et al. (2020)
32	Adoption of 6 Rs (reduce, reuse, recycle, refuse, repair, rethink) and CE practices	Adoption of the 6 Rs and Circular economy practices eventually leads to the successful implementation of sustainable practices enabled by Industry 4.0 technologies	Yadav et al. (2020), Kumar et al., (2021d), Gandhi et al. (2016)

4.3 Reachability matrix

The SSIM has been transformed into an initial reachability matrix (binary matrix) depicted in Table 8 by applying the below-mentioned rules. First, if the (i, j) value in the SSIM is V, then the (i, j) value in the reachability matrix is replaced with 1 while the (j, i) value becomes 0. Second, if the (i, j) value in the SSIM is A, then the (i, j) value in the reachability matrix is replaced with 0 while the (j, i) value becomes 1. Third, if the (i, j) value in the SSIM is X, then the (i, j) value in the reachability matrix is replaced with 1, while the (j, i) value also becomes 1. Fourth, if the (i, j) value in the SSIM is 0, then the (i, j) value in the reachability matrix is replaced with 0, while the (j, i) value also becomes 0.

The final reachability matrix has been developed from the initial reachability matrix using the transitivity rule. This rule states that if CSF 2 leads to CSF 1 and CSF 1 leads to CSF 7, then CSF 2 necessarily leads to CSF 7. Table 9 shows the final reachability matrix, which also shows the driving and dependence power. The driving power of any specific CSF is the total number of CSFs (including itself) being influenced, while the dependence power of any particular CSF means how many CSFs it is being influenced by. Hence, the driving power of any specific CSF is equal to the sum of the number of ones in the row of that CSF, and the dependence power of any particular CSF is equal to the sum of the number of ones in the column of that CSF.

Table 7 Structural self-interaction matrix (SSIM)

CSFS	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17
1	X	O	X	O	O	A	A	A	A	A	A	O	A	A	A	A
2	V	V	A	O	O	O	O	O	V	A	O	O	A	O	V	A
3	V	X	X	O	O	O	O	O	A	A	O	A	A	V	V	A
4	V	V	V	V	V	V	V	V	V	X	V	V	A	V	V	A
5	A	A	A	A	A	A	O	A	A	A	A	A	A	A	A	A
6	V	O	O	X	O	O	V	O	V	O	V	V	A	V	V	A
7	O	X	X	A	A	A	A	A	A	A	A	A	A	A	A	A
8	V	O	V	V	V	V	V	V	X	A	V	V	A	V	V	A
9	V	V	V	O	O	O	V	V	O	A	O	O	A	V	V	A
10	V	O	V	V	V	V	V	V	V	A	V	V	A	X	V	A
11	V	X	V	V	V	V	V	V	V	A	V	V	A	V	V	A
12	V	V	V	V	V	V	V	V	O	V	V	V	V	V	V	V
13	V	V	O	V	V	V	V	V	O	O	O	O	A	V	V	X
14	X	V	O	O	O	O	V	O	O	O	V	V	A	V	V	X
15	V	V	V	V	V	V	O	V	O	A	V	V	A	V	V	A
16	V	O	V	V	O	O	O	V	A	A	V	O	A	A	V	A
17	V	V	V	V	V	V	V	V	V	A	V	V	A	V	V	X
18	V	V	V	V	V	V	A	V	V	A	V	V	A	A	X	
19	X	V	V	V	V	V	A	V	V	A	V	V	A	X		
20	V	V	V	V	V	V	V	V	V	A	V	V	X			
21	O	O	A	A	A	A	A	X	X	A	X	X				
22	O	O	A	A	A	A	A	X	X	A	X					
23	V	V	V	V	V	V	V	V	O	X						
24	V	O	V	X	X	A	A	X	X							
25	V	O	V	A	A	A	A	X								
26	V	V	V	V	V	V	X									
27	V	O	V	V	X	X										
28	V	O	V	V	X											
29	V	V	V	X												
30	X	X	X													
31	X	X														
32	X															

CSFS	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	A	A	A	A	A	A	A	A	A	X	A	V	A	A	A	X
2	V	A	X	O	A	O	X	A	X	O	A	V	A	X	X	
3	O	A	X	O	A	O	X	A	X	X	A	V	A	X		

Table 7 (continued)

CSFS	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
4	V	X	V	V	A	V	V	A	V	V	V	V	X			
5	A	A	O	A	A	A	A	A	A	A	A	X				
6	V	X	X	A	A	A	X	A	X	V	X					
7	A	O	A	A	A	A	A	A	A	X						
8	V	A	X	O	A	V	X	O	X							
9	O	O	O	O	A	V	V	X								
10	V	V	A	A	A	A	X									
11	V	A	A	A	A	X										
12	V	V	V	V	X											
13	V	X	X	X												
14	V	X	X													
15	V	X														
16	X															
17																
18																
19																
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4.4 Level partitions

Level partitioning is conducted based on the final reachability matrix. At the start, the reachability and antecedent sets for each CSF are determined from the final reachability matrix. The reachability set of a particular CSF consists of the CSF itself and the other CSFs that it may influence. The antecedent set of a particular CSF comprises the CSF itself and the other CSFs that may influence it. After determining each CSF's reachability and antecedent sets, their intersection sets are identified. The CSFs for which their reachability and intersection sets are the same are given the top level (Level 1) in the ISM hierarchical model. After determining the top-level CSF(s), it is removed from the remaining sets. The same process is repeated to identify the CSF(s) for the second level and continues until each CSF level is

Table 8 Initial reachability matrix

CSFs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
2	1	1	1	0	1	0	0	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1
3	1	1	1	0	1	0	1	1	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1
4	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	1	0	1	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	1	1	0	1	0	1	0	0	1	0	0	1
7	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
8	1	1	1	0	1	1	1	1	0	1	1	0	0	1	0	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1
9	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	1	1	1
10	1	1	1	0	1	1	1	1	0	1	0	0	0	0	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1
11	1	0	0	0	1	1	1	0	0	1	1	0	0	0	0	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
13	1	0	0	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	1	1
14	1	1	1	0	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1	0	0	0	0	1	1
15	1	1	1	1	1	1	0	1	0	0	1	0	1	1	1	1	0	1	1	0	1	1	0	0	1	0	1	1	1	1	1	1
16	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	1	1	0	1
17	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1
18	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1	0	1	1	1	1	1	1
19	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
21	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0
22	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0
23	1	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
24	1	0	1	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1	0	0	1	1	1	0	1
25	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	1	0	1
26	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1
27	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	1

Table 8 (continued)

CSFs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
28	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	1
29	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	1	1	1	1
30	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1
31	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
32	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1

Table 9 Final reachability matrix

CSFs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	1*	1*	0	1	0	1	0	0	0	0	0	0	1*	0	0	0
2	1	1	1	0	1	1*	1*	1	0	1	1*	0	1*	1	1*	1	1*
3	1	1	1	0	1	1*	1	1	0	1	1*	0	1*	1	1*	1*	1*
4	1	1	1	1	1	1	1	1	1*	1	1	0	1	1	1	1	1*
5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	1	1*	1	1	1	1	0	1	1*	0	1*	1	1	1	1*
7	1	1*	1	0	1	0	1	1*	0	1*	1*	0	0	1*	0	0	0
8	1	1	1	0	1	1	1	1	0	1	1	0	1*	1	1*	1	1*
9	1	1	1	1	1	1	1	1*	1	1	1	0	1*	1*	1*	1*	0
10	1	1	1	1*	1	1	1	1	0	1	1*	0	1*	1*	1	1	0
11	1	1*	1*	0	1	1	1	1*	0	1	1	0	0	1*	1*	1	0
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1*	1*	1*	1	1	1	1*	1*	1	1	0	1	1	1	1	1
14	1	1	1	1*	1*	1	1	1	1*	1	1	0	1	1	1	1	1
15	1	1	1	1	1	1	1*	1	0	1*	1	0	1	1	1	1	1*
16	1	1*	1*	0	1	1*	1	0	0	0	0	0	0	1*	0	1*	0
17	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
18	1	1*	1*	0	1	1*	1	1*	0	0	1*	0	0	1*	0	1*	0
19	1	1*	1*	0	1	1*	1	1*	0	1	1*	0	0	1*	1*	1	0
20	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
21	1*	1*	1	0	1	0	1	1*	0	1*	0	0	0	1*	0	1*	0
22	1	0	1*	0	1	0	1	1*	0	0	0	0	0	0	0	1*	0
23	1	1	1	1	1	1*	1	1	1	1	1	0	1*	1*	1	1	1

Table 9 (continued)

CSFs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
24	1	1*	1	0	1	1*	1	1	0	1*	1*	0	0	1*	0	1	0
25	1	1*	1*	0	1	0	1	1*	0	0	0	0	0	1*	0	1*	0
26	1	1*	1*	0	1*	1*	1	1*	0	1*	1*	0	0	1*	0	1*	0
27	1	1*	1*	0	1	1*	1	1*	0	0	0	0	0	1*	0	1*	0
28	1*	1*	1*	0	1	1*	1	1*	0	0	0	0	0	1*	0	1*	0
29	1*	1*	1*	0	1	1	1	1*	0	1*	1*	0	0	1*	1*	1*	0
30	1	1	1	0	1	0	1	1*	0	1*	1*	0	0	1*	0	1*	0
31	1*	1*	1	0	1	1*	1	1*	0	1*	1	0	0	1*	0	1*	0
32	1	1*	1*	0	1	1*	1*	1*	0	1*	1*	0	1*	1	1*	1*	1*
De.P	31	30	31	11	32	25	31	29	8	24	24	1	15	30	18	29	13

CSFs	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Dr.P
1	0	1*	0	1*	1*	0	0	0	0	0	0	0	1	1*	1	12
2	1	1*	0	1*	1*	0	1	1*	1*	1*	1*	1*	1*	1	1	27
3	1	1	0	1*	1*	0	1*	1*	1*	1*	1*	1*	1	1	1	27
4	1	1	1*	1	1	1	1	1	1	1	1	1	1	1	1	31
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6	1	1	0	1	1	0	1	1*	1	1*	1*	1	1*	1*	1	28
7	1*	1*	0	1*	1*	0	0	0	0	0	0	0	1	1	1*	16
8	1	1	0	1	1	0	1	1	1	1	1	1	1	1*	1	27
9	1	1	0	1*	1*	1*	1*	1	1	1*	1*	1*	1	1	1	29
10	1	1	0	1	1	0	1	1	1	1	1	1	1	1*	1	27
11	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	25

Table 9 (continued)

CSFs	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Dr.P
12	1	1	1	1	1	1	1*	1	1	1	1	1	1	1	1	32
13	1	1	0	1*	1*	0	1*	1	1	1	1	1	1*	1	1	29
14	1	1	0	1	1	0	1*	1*	1	1*	1*	1*	1*	1	1	29
15	1	1	0	1	1	1*	1*	1	1*	1	1	1	1	1	1	29
16	1	1*	0	1*	1	0	1*	1	0	1*	1*	1	1	1*	1	20
17	1	1	0	1	1	1*	1	1	1	1	1	1	1	1	1	30
18	1	1*	0	1	1	0	1	1	0	1	1	1	1	1	1	22
19	1	1	0	1	1	0	1	1	1*	1	1	1	1	1	1	25
20	1	1	1	1	1	1*	1	1	1	1	1	1	1	1	1	31
21	1*	1*	0	1	1	0	1	1	0	0	1*	1*	1*	1*	1*	20
22	0	0	0	1	1	0	1	1	0	0	1*	1*	1*	1*	1*	15
23	1	1	1	1	1	1	1*	1	1	1	1	1	1	1	1	31
24	1*	1*	0	1	1	0	1	1	1*	1*	1	1	1	1*	1	24
25	0	1*	0	1	1	0	1	1	0	0	1*	1*	1	1*	1	18
26	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	24
27	0	1*	0	1	1	0	1	1	0	1	1	1	1	1*	1	20
28	0	1*	0	1	1	0	1	1	0	1	1	1	1	1*	1	20
29	1*	1*	0	1	1	0	1	1	1*	0	1*	1	1	1	1	24
30	1*	1*	0	1	1	0	1*	1*	0	0	0	0	1	1	1	19
31	1*	1*	0	1*	1*	0	1*	1*	1*	1*	1*	1*	1	1	1	24
32	1*	1	0	1*	1*	0	1*	1*	1*	1*	1*	1*	1	1	1	27
De.P	26	30	4	31	31	7	29	29	21	24	28	28	31	31	31	

Dr.P. Driving power, *De.P.* Dependence power determined. Table 10 shows the reachability set, antecedent set, and intersection set, along with the different levels that the respective CSF(s) occupy. The process of identification of the levels of each CSF has been carried out in 11 iterations. These levels help in developing the digraph and ISM model.

4.5 Development of the digraph

Based on the final reachability matrix, an initial directed graph (digraph), including the transitive links, has been developed. The digraph thus formed is complex in nature. Hence, the final digraph has been developed by removing the transitivity links from the initial digraph. If a relationship exists between CSFs i and j, it is depicted by an arrow pointing from i to j, and a digraph is constructed. Figure 10 shows the final directed graph consisting of various CSFs at different levels. The CSF(s) with level 1 are placed at the top of the digraph, and CSFs with level 2 are placed at the next level. The process is continued until all the CSFs are placed at the remaining levels of the digraph.

4.6 Formation of the ISM model

The ISM model is formed by substituting the serial number of CSF nodes, as shown in the final digraph (Fig. 10), with the CSF statements. The relationships among the CSFs are obtained from the final digraph. Figure 11 shows the final ISM model obtained after the conceptual consistency check and the vital modifications in the model.

4.7 MICMAC analysis

The present study used MICMAC analysis to classify the CSFs into four clusters based on their driving and dependence power. These four clusters, namely “Autonomous CSFs”, “Dependent CSFs”, “Linkage CSFs”, and “Independent CSFs” have been presented in Fig. 12.

The four clusters can be explained as follows. (i) *Autonomous CSFs:* The CSFs that come under this category (cluster) have weak driving power and weak dependence power. Relatively these CSFs are isolated from the system, with which they have few links that may be strong. No CSF comes under the “Autonomous CSFs” cluster in the present work. (ii) *Dependent CSFs:* This cluster consists of the CSFs which have poor driving power but a strong dependence power. (iii) *Linkage CSFs:* The CSFs included under this cluster have strong driving and dependence power. (iv) *Independent CSFs:* These CSFs have strong driving power but weak dependence power. It is clear from Fig. 12 that CSF 12 (“Governmental support and policies”) has the highest driving power while CSF 5 (“Cost reduction”) has the highest dependence power.

Table 10 Level partitions for CSFs (Iteration 1–11)

CSFs	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 7, 14, 19, 21, 22, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 7, 14, 19, 21, 22, 30, 31, 32	2nd
2	2, 6, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 24, 25, 26, 27, 28, 29	2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 6, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 24, 25, 26, 27, 28, 29	3rd
3	1, 2, 3, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32	2nd
4	4, 9, 13, 15, 17, 20, 23	4, 9, 12, 13, 15, 17, 20, 23	4, 9, 13, 15, 17, 20, 23	7th
5	5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	5	1st
6	4, 6, 8, 10, 11, 13, 15, 17, 18, 26, 27	4, 6, 8, 9, 10, 11, 12, 13, 15, 17, 18, 20, 23, 26, 27	4, 6, 8, 10, 11, 13, 15, 17, 18, 26, 27	4th
7	1, 2, 3, 7, 8, 10, 11, 14, 18, 19, 21, 22, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 7, 8, 10, 11, 14, 18, 19, 21, 22, 30, 31, 32	2nd
8	6, 8, 10, 11, 13, 15, 17, 18, 26, 27	4, 6, 8, 9, 10, 11, 12, 13, 15, 17, 18, 20, 23, 26, 27	6, 8, 10, 11, 13, 15, 17, 18, 26, 27	4th
9	9, 23	9, 12, 17, 20, 23	9, 23	8th
10	4, 10, 11, 13, 15, 26	4, 9, 10, 11, 12, 13, 15, 17, 20, 23, 26	4, 10, 11, 13, 15, 26	6th
11	10, 11, 15, 26	4, 9, 10, 11, 12, 13, 15, 17, 20, 23, 26	10, 11, 15, 26	6th
12	12	12	12	11th
13	4, 9, 13, 15, 17	4, 9, 12, 13, 15, 17, 20, 23,	4, 9, 13, 15, 17	7th
14	2, 4, 6, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 24, 25, 26, 27, 28, 29	2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 4, 6, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 24, 25, 26, 27, 28, 29	3rd
15	4,13, 15, 17, 23	4, 9, 12, 13, 15, 17, 20, 23	4, 13, 15, 17, 23	7th
16	2, 6, 14, 16, 18, 19, 24, 25, 27, 28, 29	2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 6, 14, 16, 18, 19, 24, 25, 27, 28, 29	3rd

Table 10 (continued)

CSFs	Reachability set	Antecedent set	Intersection set	Level
17	17	12, 17, 20	17	9th
18	11, 18	4, 9, 10, 11, 12, 13, 15, 17, 18, 20, 23, 26	11, 18	5th
19	2, 6, 8, 10, 11, 14, 15, 16, 18, 19, 24, 25, 26, 27, 28, 29	2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 6, 8, 10, 11, 14, 15, 16, 18, 19, 24, 25, 26, 27, 28, 29	3rd
20	20	12, 20	20	10th
21	1, 2, 3, 7, 8, 10, 14, 16, 18, 19, 21, 22, 24, 25, 28, 29, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 7, 8, 10, 14, 16, 18, 19, 21, 22, 24, 25, 28, 29, 30, 31, 32	2nd
22	1, 3, 7, 8, 16, 21, 22, 24, 25, 28, 29, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 3, 7, 8, 16, 21, 22, 24, 25, 28, 29, 30, 31, 32	2nd
23	9, 17, 20, 23	9, 12, 17, 20, 23	9, 17, 20, 23	8th
24	2, 6, 8, 10, 11, 14, 16, 18, 19, 24, 25, 26, 27, 28, 29	2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 6, 8, 10, 11, 14, 16, 18, 19, 24, 25, 26, 27, 28, 29	3rd
25	2, 8, 14, 16, 19, 24, 25, 28, 29	2, 4, 6, 8, 9, 10 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 8, 14, 16, 19, 24, 25, 28, 29	3rd
26	10, 11, 26	4, 9, 10, 11, 12, 13, 15, 17, 20, 23, 26	10, 11, 26	6th
27	6, 8, 27	4, 6, 8, 9, 10, 11, 12, 13, 15, 17, 18, 20, 23, 26, 27	6, 8, 27	4th
28	2, 6, 8, 14, 16, 19, 24, 25, 27, 28, 29	2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 6, 8, 14, 16, 19, 24, 25, 27, 28, 29	3rd
29	2, 6, 8, 10, 11, 14, 15, 16, 18, 19, 24, 25, 26, 28, 29	2, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29	2, 6, 8, 10, 11, 14, 15, 16, 18, 19, 24, 25, 26, 28, 29	3rd
30	1, 2, 3, 7, 8, 10, 11, 14, 16, 18, 19, 21, 22, 24, 25, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 7, 8, 10, 11, 14, 16, 18, 19, 21, 22, 24, 25, 30, 31, 32	2nd

Table 10 (continued)

CSFs	Reachability set	Antecedent set	Intersection set	Level
31	1, 2, 3, 6, 7, 8, 10, 11, 14, 16, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 6, 7, 8, 10, 11, 14, 16, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32	2nd
32	1, 2, 3, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	1, 2, 3, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32	2nd

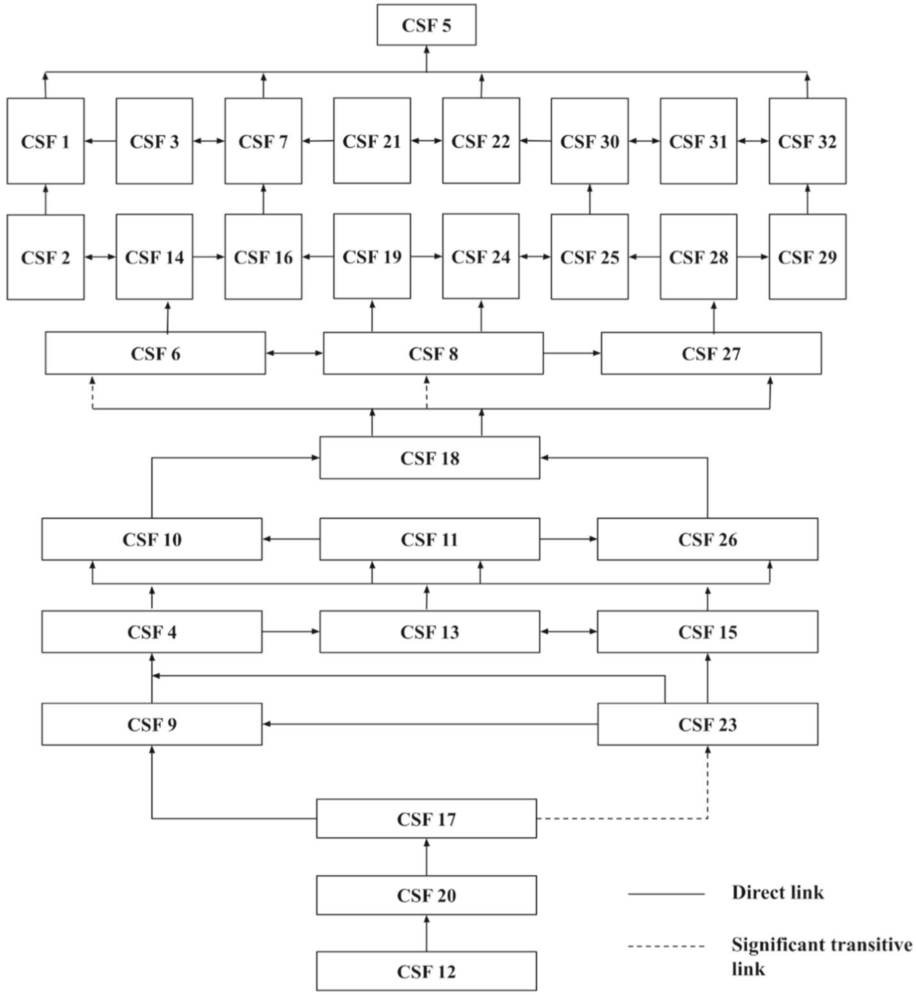

Fig. 10 Final digraph

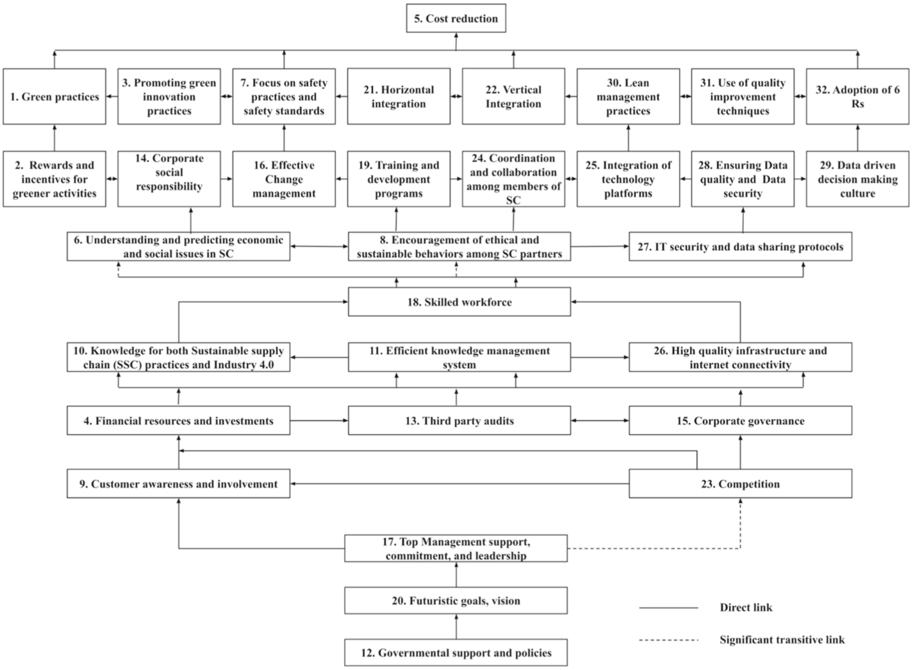

Fig. 11 ISM model

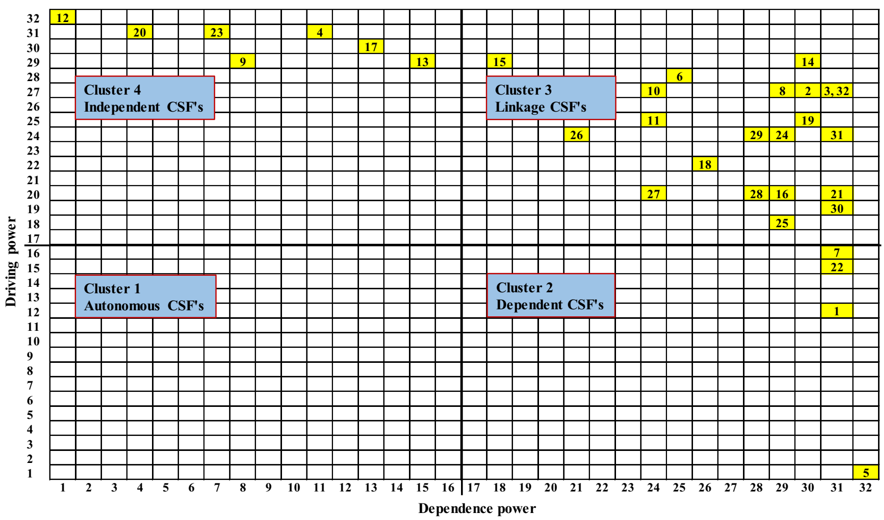

Fig. 12 MICMAC analysis of CSFs

5 Results and discussion

5.1 Results

This study provides a detailed analysis of the industry 4.0 technologies integrated SSC area using SLR, bibliometric analysis, and ISM–MICMAC analysis. The SLR shows that the research in the selected domain has been increasing over the five years period to 2022. It also shows the importance of the combined study of Industry 4.0 technologies and sustainability for the betterment of industries and society. Based on the research gaps identified through the SLR, this study analyzes 32 CSFs that are crucial to adopting SSC practices in the Industry 4.0 era, and their interrelationships examined using the ISM method and MICMAC analysis. As the Indian manufacturing sector is one of the fastest-growing sectors in India, the experts for the study have been selected from the same sector and academia. Based on the experts' opinion, the SSIM of 32 CSFs has been developed. Level partitioning shows a requirement of 11 iterations to determine the level of each CSF. This resulted in the development of the digraph and ISM model. Further, MICMAC analysis has been performed to group the CSFs into four clusters based on their driving and dependence powers.

From the ISM model, as shown in Fig. 11, it can be understood that CSFs from the top levels (Level 1 to level 6) have less influencing power as compared to the CSFs below them (level 7 to level 11). Thus, cost reduction is the least significant CSF compared to the others for adopting Industry 4.0 integrated SSC practices. The CSFs from the ISM model can be classified into three distinct levels: Top-level, intermediate-level, and bottom-level. Bottom-level CSFs are the most important ones because they can greatly influence the other CSFs that fall above them. "Governmental support and policies", "Futuristic goals, vision", "Top Management support, commitment, and leadership", "Competition", and "Customer awareness and involvement" are some of the significant CSFs to adopt Industry 4.0 integrated SSC practices. Further, MICMAC analysis (Fig. 12) has shown the classification of CSFs based on their driving and dependence powers. It is found that no single CSF belongs to the "Autonomous CSFs" category of MICMAC analysis. Cluster 2, "Dependent CSFs" includes four CSFs ("CSF 1, CSF 5, CSF 7, CSF 22") that have less driving power and more dependence power. The CSFs coming under cluster 3 "Linkage CSFs" are considered the most important ones because any action taken on them may affect the entire system. Figure 12 shows that 21 CSFs fall under cluster 3 while 7 CSFs fall under cluster 4, "Independent CSFs".

Based on the detailed analysis and outcome of the study, it is observed that support from the government in terms of finance, regulations, and policies, and top management commitment to the environment and achieving sustainable performance leads to the development of different organizational capabilities. These drivers motivate organizations to develop technological capabilities that aid in adopting emerging Industry 4.0 technologies which further lead to organizational performance. These observations and arguments are supported by recent research studies (Atasu et al., 2020; Dubey et al., 2022a, 2022b; Fatorachian & Kazemi, 2021; Kamble & Gunasekaran, 2021; Olsen & Tomlin, 2020; Sharma et al., 2021; Shibin et al., 2020; Talapatra et al., 2019). Thus, a theoretical model is developed that depicts how "Government support and policies", and "Top management commitment" lead to "Sustainable performance", and "Overall cost reduction" through various linkages and mediating mechanisms. The developed model, as shown in Fig. 13, is deeply rooted and backed by theories such as Institutional theory (Asif et al., 2020; Chu et al., 2017; DiMaggio & Powell, 1983; Glover et al., 2014; Hirsch, 1975; Sarkis et al., 2011), Resource-based view (RBV) (Barney, 1986; Grant, 1996), Systems theory (Dubey et al., 2017a, 2017b, 2017c; Fatorachian

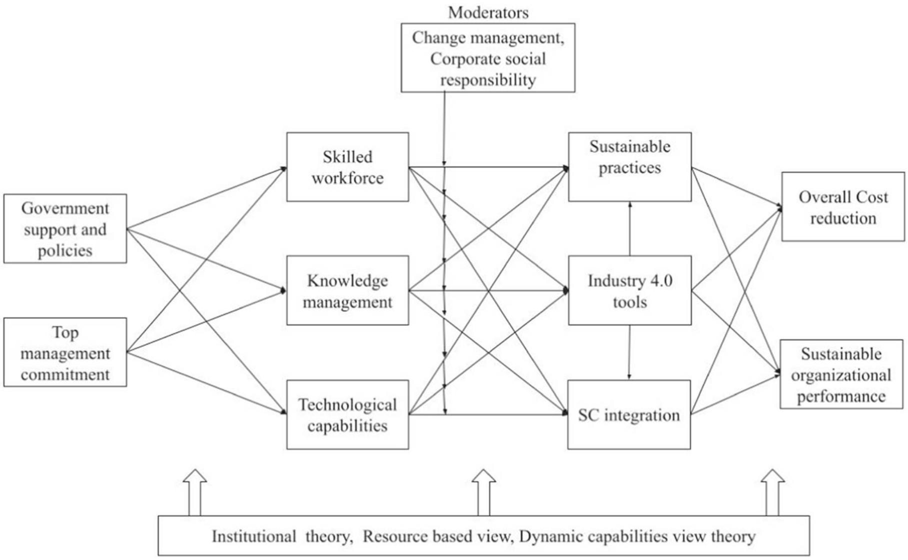

Fig. 13 Theoretical model

& Kazemi, 2021) and Dynamic capabilities view (DCV) (Belhadi et al., 2021; Teece et al., 1997). In this manner, the synthesis of ISM and MCMAC analysis results in the development of a theoretical model.

6 Discussion

The rationale behind the selection of the IP theory, RBV, and DCV in developing the theoretical model can be primarily given in the following ways. First, the three dimensions of sustainability namely economic, environmental, and social can be better explained with the help of a combination of IP theory, RBV, and DCV. RBV helps to understand the economic dimension of sustainability with an acute focus on the internal strategic resources and the decisions of firms based on economic rationality whereas IP theory aids in understanding the social and environmental dimensions of sustainability (Oliver, 1997; Shibin et al., 2020). Second, to cater to the needs of the uncertain business environment, firms need to reconfigure their existing capabilities and develop new dynamic capabilities. Thus, the DC approach, an extension of RBV is needed to avoid the core rigidities and develop a new bundle of strategic resources (R. Sharma et al., 2022). In this regard, firms need to comply with the legal standards, policies, and social pressures, to mimic successful companies wherever required, to protect existing unique, valuable resources, and at the same time to develop new competencies for achieving long-term competitive advantage. Thus, the combination of IP, RBV, and DCV approaches is the best fit to understand the complexity associated with SSC operations and to analyze the sustainable SC performance in terms of all three dimensions of sustainability.

DiMaggio and Powell (1983) identified three forms of institutional pressures: "coercive", "normative" and "mimetic". Coercive pressure refers to the external pressure exerted by top-level entities like the government and regulatory bodies, normative pressures are exerted by various stakeholders like customers, suppliers, or social groups, and mimetic pressures are competitive pressures in which companies try to mimic the other successful competitive companies to avoid the risk (Asif et al., 2020; Champion et al., 2014; Chu et al., 2017; Sarkis et al., 2011). On the other hand, the developed ISM model also depicts the importance of "Government support and policies", "Competition", "Customer awareness", and similar critical factors in driving the adoption of sustainable practices in the Industry 4.0 era. These driving factors can be considered as part of coercive pressures (CP), normative pressures (NP), and mimetic pressures (MP) of the IP theory. The intricate interrelations of these factors with the other factors of the ISM model such as "Top management support, commitment, and leadership", and "Efficient knowledge management system", etc. can be explained with the help of IP theory. This is because IP theory is suitable for explaining how managerial decisions are shaped by the social context of the firms and how the external forces push the firms to implement Industry 4.0 technologies-enabled SSC practices. Thus, based on the prior literature (Ahmed et al., 2019; Bag, et al., 2021a, b, c; Glover et al., 2014; Gupta et al., 2020) and the developed ISM model, IP theory is found to be the natural choice for explaining the theoretical model. However, it is also observed that IP theory has certain limitations in explaining intra-organizational dynamics. Although IP leads organizations towards conforming to the institutional norms, it fails to explain why there exist differences in the firms in selecting strategic resources despite the same institutional pressures (Colwell & Joshi, 2013; Deephouse, 1996; Scott, 2008).

The interplay among the mechanisms through which strategic resources and capabilities like "Technological capabilities", "Skilled workforce", "SC integration", "SSC practices, and waste reduction capabilities" lead to sustained competitive advantage can be explained in detail with the help of RBV (Barney et al., 2001; Shibin et al., 2020) and DCV (Teece et al., 1997). RBV is an extensively used and popular theory in the Operations and SCM literature (Bowen et al., 2001; Carter & Easton, 2011; Dubey et al., 2019a, 2019b; Gunasekaran et al., 2017; Hunt & Davis, 2012; Wamba et al., 2017). RBV perspective helps firms to utilize the inherent unique, valuable, and non-substitutable resources and aids in the optimization of resources based on economic goals (Barney et al., 2001; Oliver, 1997). RBV in SSCM explains how competitive advantage can be gained by using sustainable competencies (Touboulic & Walker, 2015). Despite its popularity, RBV also attracts criticism that it fails to look beyond the characteristics of resources and the resource market to explain the firm's heterogeneity. It is also less focused on the social context in which decisions pertaining to resource selection are made (Oliver, 1997; Shibin et al., 2020). Thus, following the arguments of Colwell and Joshi (2013), Shibin et al. (2020), and Oliver (1997), IP and RBV are used in combination to explain the theoretical model.

Further, DCV, a complementary approach to the RBV has also been used along with IP and RBV. Implementation of SSC practices in the volatile market poses certain challenges such as managing the resistance from employees to the new changes, minimizing the production losses, selecting green and sustainable suppliers, complex energy and material flows, proper integration of the SC activities and the real-time monitoring of the SC processes (Chari et al., 2022; R. Sharma et al., 2022). In order to gain sustained competitive advantage in the rapidly changing business environment, organizations need to adjust their static competencies and develop dynamic capabilities. Thus the combination of IP theory, RBV, and DCV helps to look beyond the survival, and legitimacy outcomes (Colwell & Joshi, 2013; Shubham et al., 2018), to avoid the rigidities that may occur due to the ignorance towards the needs of the uncertain business environment (R. Sharma et al., 2022), to achieve long term competitive advantage and to develop the innovative bundle of strategic resources.

The theoretical model shown in Fig. 13 serves as the foundation for the propositions.

Institutional Theory explains how the organizational practices of companies are influenced by various external pressures (Hirsch, 1975). Recent literature also exhibits that government policies regarding environmental laws, top management environmental commitment, and other institutional pressures have motivated organizations to adopt sustainable practices (Ahmed et al., 2019; Chu et al., 2017). Prior literature suggests that the lack of digital skills and green skills is one of the vital barriers to the adoption of sustainable practices (Alavi & Aghakhani, 2023; S. Kumar et al., 2021d; Raj et al., 2020) The skilled workforce having a better understanding of environmental laws and practices, ability to quickly learn and utilize the new technologies, and ability to use resources efficiently help organizations to implement sustainable practices in the Industry 4.0 era. Such skilled employees can make the utmost utilization of the potential hidden in the application of Industry 4.0 technologies for high SC integration and better implementation of sustainable practices. Government support in terms of awareness campaigns pertaining to sustainability and digitalization, training and development for building a new set of skills, policy-making, provision of subsidies, and rewards to firms for better sustainable performance help firms to upskill their employees and push them for learning a new set of green and digital skills (A. Kumar et al., 2021a; S. Kumar et al., 2021d; Narayanan et al., 2019) In addition, environmentally conscious top management drives the development of green corporate culture, encourages employees to think green and be creative, facilitates their professional development through workshops, and encourages them to gain digital skills to promote the adoption of sustainable practices (Banik et al., 2020; Chu et al., 2017; de Sousa Jabbour et al., 2018; A. Kumar et al., 2019; Malviya et al., 2016; Saroha et al., 2020).

Similarly, knowledge management aids in implementing sustainable practices in the Industry 4.0 era. Knowledge management (KM) is defined as "the systematic management of all activities and processes referred to generation and development, codification and storage, transferring and sharing, and utilization of knowledge for an organization's competitive edge" (Zaim, 2006, p. 3). Efficient KM helps firms in generating and sharing the knowledge that results in the adoption of Industry 4.0 technologies enabled sustainable practices (A. Kumar et al., 2021a). For achieving higher sustainable performance in economic, social, and environmental dimensions of sustainability, firms need to comply with the sustainability guidelines and create a knowledge sharing, and learning environment (Martins et al., 2019). Government support and policies regarding sustainable development and digitalization push firms to acquire, store, and transfer the knowledge related to Industry 4.0 enabled sustainable practices (Adhikari & Shrestha, 2022; Demir et al., 2023; Martins et al., 2019). In addition, commitment and support from top management also enable knowledge sharing and learning culture in the organizations (Bucci & El-Diraby, 2018; Lim et al., 2017). Along the same lines, it has been found that organizations in today's dynamic business environment are adopting emerging Industry 4.0 technologies which not only enable sustainable practices but also help to gain a competitive advantage (Bhatia & Kumar, 2022). Thus, institutional pressures and environmental commitment of the firms push them to adopt Industry 4.0 technologies and sustainable practices to gain higher sustainable performance and competitive advantage. In doing so, to achieve sustainable performance, it is crucial for firms to develop technological capabilities for better utilization of Industry 4.0 technologies. Thus, it is argued that "Government support and policies" and "Top management support, leadership, and commitment" lead to a "Skilled workforce", "Efficient KM", and the development of "Technological capabilities" that result in the adoption of Industry 4.0 enabled SSC practices and better SC integration.

Additionally, based on the Resource-based view (RBV), it is observed that firms can obtain a competitive advantage by using a bundle of strategic resources and capabilities (Barney, 1986). Resources can be classified into "human resources", "technological capabilities", "financial resources" etc. Barney (1986) suggests four attributes of the resources as "valuable (V), rare (R), non-imitable (I), non-substitutable (N)". On the other side, DCV extends the RBV logic, which can also be considered complementary to the RBV. Dynamic capabilities (DC), as defined by Teece et al. (1997), are "the firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments" (p. 516). The DC approach helps firms operating in the dynamic business environment to achieve higher competitive advantages and leads to developing an innovative strategic bundle of resources and does not permit rigidities (Sharma et al., 2022). Thus, "Skilled workforce", "Knowledge management", and "Basic technological capabilities" lead to the development of new organizational capabilities such as the implementation of sustainable SC practices (waste reduction, sustainable production, eco-design, etc.), effective use of the Industry 4.0 technologies for promoting integration, innovation, and environmental performance, and high level of integration in the entire SC processes. As a result, improved SCI and SSC practices supported by the efficient use of Industry 4.0 tools may serve as a unique bundle of competencies to gain a continuous competitive advantage and superior sustainable performance. Based on these arguments rooted in the IP theory, RBV, and DCV, it can be proposed that:

Proposition 1 Government support and policies have a positive effect on sustainable practices, Industry 4.0 technologies, and SC integration under the mediating effect of a skilled workforce, knowledge management, and technological capabilities.

Proposition 2 Top management commitment has a positive effect on sustainable practices, Industry 4.0 technologies, and SC integration under the mediating effect of a skilled workforce, knowledge management, and technological capabilities.

Further, it is observed that sustainable practices like sustainable manufacturing, green processing, product innovation, eco-design, etc., lead to sustainable organizational performance (Cheng et al., 2021; El-Kassar & Singh, 2019; Singh et al., 2022; Zeng et al., 2017). Recent literature has directed that emerging Industry 4.0 technologies play a vital role in enabling these SSC practices (Bag et al., 2018; Kamble et al., 2020; Machado et al., 2020; Sun et al., 2021). Also, supply chain integration (SCI) includes collaboration among the supply chain members to improve supply chain performance and efficiency and satisfy customer demands. Elements like information sharing, trust, connectivity, IT infrastructure, and top management participation play a crucial role in achieving SCI (Shibin et al., 2020). Integrated business processes of the supply chain partners, along with timely information sharing, help to achieve cost optimization and higher performance. The requirement of real-time information sharing, secure transactions, high connectivity, products, and process integration can be effectively achieved by using Industry 4.0 technologies (Di Maria et al., 2022; Sharma et al., 2022). Based on these arguments, research propositions 3 and 4 have been put forward as follows:

Proposition 3 Sustainable practices and SC integration positively impact overall cost reduction and sustainable organizational performance.

Proposition 4 Industry 4.0 technologies have a positive impact on sustainable practices, SC integration, overall cost reduction, and sustainable organizational performance.

It is found that factors such as "skilled workforce", "knowledge management", and "technological resources" have differential impacts on "sustainable practices", "Industry 4.0 technologies", and "SC integration'. However, these impacts can be explained with the help of

"Effective change management", and "Corporate Social Responsibility (CSR)" as moderating constructs. The utilization of skills of the employees towards sustainability, employees' ability to adopt the new technological changes, and better knowledge utilization (Demir et al., 2023), depends on various factors such as employees' organizational commitment, their sense of job security in light of adopting new technologies, their knowledge sharing behavior, the availability of training and development opportunities, and the culture of organizations. Along the same lines, in the era of digitalization, the changes have become radical, continuous, and complex. To cope with such challenges and continuous changes, firms need to develop strategies, so that they can mitigate resistance from the employees and motivate them to utilize their potential for achieving organizational goals. In this vein, it is observed that "CSR" and "Effective change management" practices help firms to develop trust and commitment among employees for the organization, to enhance knowledge-sharing behavior, and to reduce the resistance to change resulting in the adoption of SSC practices in the Industry 4.0 era (Farooq et al., 2014; A. Kumar et al., 2021a, 2021b, 2021c; Lu et al., 2020; Nejati et al., 2017; Thakur & Mangla, 2019; Turker, 2009; Wang et al., 2020). CSR motivates businesses to identify the needs of stakeholders and raise environmental and societal values while reducing the occurrence of environmental problems (Wang et al., 2020). CSR consists of internal CSR and external CSR, where "Internal CSR involves actions intended to benefit employees (i.e., the self, given our focus on employee reactions to CSR), whereas external CSR involves actions intended to benefit external stakeholders (i.e., others)" (Farooq et al., 2017, p. 559). Internal CSR inspires employees to think positively about their firms and improves their creativity which in turn aids in implementing SSC practices. External CSR refers to activities that target management practices of local communities, the natural environment, or consumers (Wang et al., 2020). Thus, firms performing CSR (internal and external) can add value to the environment and society and successfully implement SSC practices. In this way, the impact of skills of employees, KM, and technological capabilities on the Industry 4.0 enabled sustainable practices can be strengthened by using CSR and effective change management strategies. Based on these arguments, the following two propositions are presented:

Proposition 5 Change management may positively moderate the relationship between a skilled workforce, knowledge management, technological capabilities, sustainable practices, Industry 4.0 technologies, and SC integration.

Proposition 6 Corporate social responsibility may positively moderate the relationship between a skilled workforce, knowledge management, technological capabilities, and sustainable practices.

6.1 Theoretical contribution

The development of the theoretical model and the propositions is motivated by the research work by Dubey et al., (2022a, 2022b). In the present study, the complex relationships between the CSFs have been simplified using the ISM model and further clarified by the theoretical model and six propositions. The findings of this study and the propositions developed are supported by recent research by Bhatia and Kumar (2022); Jabbour et al. (2018); Khan et al., (2021a, 2021b, 2021c); and A. Kumar et al., (2021a, 2021b, 2021c). The arguments have been critically investigated by analyzing prior literature studies and ensuring logical congruency in the context of the selected domain (Whittemore et al., 2001). To ensure validity, the interpretations are carefully analyzed by including multiple sources and methods. This also helps to incorporate triangulation by avoiding the reliability of a single source of information (Iyengar et al., 2017; Jack & Raturi, 2006). From the theoretical model and propositions, it is clear that "government support and policies", and "top management commitment" emerge as the prime driving factors for developing strategic resources and capabilities related to Industry 4.0 technologies integrated SSC practices. Management's commitment to the environment, along with other institutional pressures, leads to developing organizational competencies such as a skilled workforce, technological capabilities, and effective knowledge management abilities. These strategic resources aid in adopting emerging technologies which further helps to adopt sustainable practices and achieve high SC integration. Implementation of such practices and technological advancements in organizations leads to sustained competitive advantage and sustainable performance. This suggests that organizations must develop dynamic capabilities in the volatile business environment despite focusing on short-term operational capabilities. Thus, the significant theoretical contributions made by this study are: (i) The present study addresses the calls to resolve the confusion about CSFs and their relations. This is done by using the SLR, bibliometric analysis, qualitative interviews in association with ISM–MICMAC analysis, and detailed synthesis of the ISM–MICMAC analysis resulting in the theoretical model. (ii) A theoretical model and the six propositions are built based on organizational theories like RBV, DCV, and Institutional theory. The current study also explains the importance of the DCV in the volatile business environment and depicts the strategies to deal with IP. It is also discussed that to cater to the needs of the changing market, firms need to transform their steady-state resources into dynamic capabilities by reconfiguring and renewing their existing capabilities. The extant study demonstrates how capabilities related to high SC integration, implementation of Industry 4.0 technologies, and SSC practices lead to a continuous competitive advantage. In this regard, it is observed that these higher-order capabilities can be developed by using a bundle of resources like "skilled workforce", "technological resources", and "knowledge management" while dealing with institutional pressures; Thus, the theoretical model helps to understand the intertwined linkages between Industry 4.0 technologies and SSC practices which further lead to higher performance and sustained competitive advantage. This model adds to the literature on sustainability in the Industry 4.0 era by using the combination of the three theories like IP, RBV, and DCV. (iii) The use of SLR and bibliometric analysis provides the recent trends, topics, and interactions among countries, keywords, journals, etc. This helps to locate the future research avenues of the sustainability area in the Industry 4.0 era.

6.2 Managerial implications

Government initiatives, policies, environmental laws, and worldwide awareness of stakeholders regarding the importance of sustainability, competitive advantage, and other factors have pushed industries to adopt both Industry 4.0 technologies and sustainable practices. The Indian manufacturing sector has made considerable progress over the past two decades and is expected to grow at a rapid pace in the future. The present study is helpful to policymakers, industry leaders, and managers in many ways, such as: (i) This study aids managers, especially from the manufacturing domain, to identify the CSFs needed to adopt and implement Industry 4.0 technologies integrated SSC practices. The complexities of the relationships among CSFs are clarified by the ISM and theoretical models. At the start, managers can simply focus on the CSFs, which have high driving power and low dependence power, as shown through the MICMAC analysis. (ii) The theoretical model provides clarity for managers regarding the development of strategic resources like "Skilled workforce", "Technological capabilities", and "Knowledge management". Firms that possess these resources should consider transforming, reconfiguring, and mobilizing them to cater to the changing business environment demands. Such reconfiguration and transformation will lead to the development of an innovative bundle of higher dynamic capabilities such as the ability to reduce waste, achieve higher SC integration, effective implementation of SSC practices, ability to select and utilize relevant emerging technologies, build Industry 4.0 capabilities, etc. Such new dynamic capabilities will keep firms ahead of their competitors and help them to gain higher sustainable performance and competitive advantage. The propositions establish the way forward in detail for further analysis and investigation by researchers and managers to gain sustainable performance. This study aids in formulating effective strategies for successfully adopting Industry 4.0 technologies integrated SSC practices. iii) The theoretical model highlights the importance of "CSR" and "Effective change management". Thus, managers can analyze that firms that implement CSR practices lead to innovative green practices, better coordination among employees, increased creativity, and ultimately higher sustainable performance. In the same way, effective change management strategies, training and development programs, and knowledge management practices enable firms to adapt to the demands of the volatile business environment quickly.

7 Conclusion and future directions

7.1 Conclusion

The current study provides a comprehensive analysis and detailed discussion regarding Industry 4.0 technologies integrated SSC practices using SLR, bibliometric analysis, and ISM-MICMAC analysis and further develops a theoretical model and propositions. Based on the SLR and discussions with the industry and academic experts, CSFs that are crucial to adopt Industry 4.0 technologies integrated SSC practices are enlisted. The ambiguous and complex linkages among these CSFs are clarified using the ISM methodology. The bottom levels of the ISM model depict the significance of "Governmental support and policies", "Top Management support, commitment, and leadership", "Competition", "Customer awareness", etc., due to their high driving powers. From this, it can be concluded that the adoption of emerging technologies and sustainable practices is driven by the various institutional pressures, leadership, and environmental commitment of the firms' management. These pressures and effective leadership lead to the development of organizational strategic competencies, which are vital to adopting Industry 4.0 tools and sustainable practices. Propositions 5 and 6 have shown the impact of moderators "Change management" and "Corporate social responsibility" on the relationships between "Skilled workforce", "Knowledge management", "Technological capabilities", and "Sustainable practices", and "Industry 4.0 technologies" and "SC integration". Although the contextual relationships between CSFs are based on the opinion of experts from the Indian manufacturing sector, they can be generalized to the other manufacturing industries from various emerging economies. A theoretical model has been proposed to illustrate the comprehensive ISM model. The significance of this study lies in various ways, as follows: (i) This study is unique in providing a detailed discussion on CSFs of Industry 4.0 technologies integrated SSC practices along with the use of rigorous methods that include SLR, bibliometric analysis, and ISM -MICMAC analysis. (ii) The propositions and model are built upon theories such as RBV, DCV, and IP. Thus, the present study has added new dimensions to the current application of these theories. The use of IP along with the RBV supports the arguments by Oliver (1997) concerning the integration of IP and RBV to describe managerial decisions. Further, to cater to the volatile business environment and to gain sustained competitive advantage by the development of an innovative bundle of new capabilities, the DCV along with IP and RBV is used. (iii) Managers and industry leaders will be benefitted by focusing on the crucial driving CSFs depicted in the independent cluster of MICMAC analysis. They will also get a clear idea from the theoretical model about developing various capabilities to adopt Industry 4.0 technologies integrated SSC practices successfully. (iv) This study will aid researchers in understanding the novel approach and application of multistage analysis, including SLR, descriptive and bibliometric analysis, and ISM–MICMAC analysis.

7.2 Limitations and future research directions

The present study has tried to utilize the potential of interpretive logic to build a theoretical model and attempted to provide a detailed discussion of the relationships among CSFs. However, like all studies, this study has certain limitations. Limitations of this study are as follows: First, the ISM model and contextual relationship between CSFs are based on the opinions of the selected small number of experts. This small sample size is not sufficient to provide statistical validation. Thus, the proposed theoretical framework can be further validated by modulation of the nature and size of the sample. Second, there may arise an issue of generalizability of the findings in other developing countries. Nevertheless, a number of common CSFs are relevant to the manufacturing industries irrespective of their home countries. Thus, the study can be extended to the manufacturing sector of other emerging economies of the world. Third, in the analysis of the current study, the strength (weak, strong, or medium) of the relationship among the CSFs is not considered. This study has considered the relationships in a binary fashion, like 1 (relationship among CSF exists) or 0 (relationship among CSFs does not exist). Thus, Fuzzy MICMAC analysis can be performed in future studies to avoid this limitation. Based on these limitations, there exist various potential avenues for future research.

In the present study, SLR, bibliometric analysis, and qualitative interviews in combination with ISM–MICMAC analysis have been used. However, future studies can extend this research approach by including TISM (Sushil, 2012) along with qualitative interviews and focused group discussions. As the ISM method lacks clarity in terms of transitive links and causality, the use of TISM may overcome these limitations of ISM (Luo et al., 2018; Sushil, 2012). From the theoretical point of view, the present study has combined the IP, RBV, and DCV and tried to explain the complexities associated with the adoption of SSC practices along with Industry 4.0 technologies. However, further studies can build upon the absorptive capacity theory, stakeholders' theory, systems theory, and other relevant theories. Although the combination of IP, RBV, and DCV is effective, there exist certain limitations. The resources and capabilities introduced by RBV, and DCV respectively may not always add value (Belhadi et al., 2022; Hitt et al., 2016). Also, except for a few firms, it is difficult to develop such unique, rare, inimitable resources and achieve high-level capabilities for other average small firms which make small but important progress (Dubey et al., 2022a, 2022b). Rather, these firms can utilize readily available imitable practices to impact their performance. In this regard, the practice-based view (PBV) as introduced by Bromiley and Rau (2014) can be used as an alternative theoretical approach to the RBV. Future research can use the PBV along with RBV, DCV, contingent theory, and other suitable organizational theories (Bag et al., 2021a, 2021b, 2021c; Belhadi et al., 2022; Dubey et al., 2022a, 2022b). In the future, researchers can empirically test the proposed theoretical model using Structural Equation Modeling (SEM) based on the large sample size and structured questionnaire. Future studies can enquire about the effect of CSR on SSC practices in the Industry 4.0 era. It will be interesting to analyze how CSR and emerging technologies together lead to better performance. The impact of Industry 4.0 technologies on the social aspect of sustainability, like employability, health, safety, equality, etc., is an interesting topic for future empirical investigation. Even, future studies can develop the model based on the qualitative investigation to find the impact of emerging technologies on socially sustainable practices and further test the model.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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