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An analysis of the strategies for overcoming digital supply chain implementation barriers

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ABSTRACT

This study aims to identify and prioritize the strategies for overcoming digital supply chain (DSC) implementation barriers. Twenty-five DSC barriers and seventeen DSC strategies are formulated through an extensive literature review and expert discussion. An integrated Modified Stepwise Weight Assessment Ratio Analysis (SWARA) and Combined Compromise Solution (CoCoSo) based framework has been used to fulfil the research objective. A case study in the automotive industry is undertaken to assess the applicability of the proposed framework. With the help of experts, a pairwise comparison matrix has been developed for critical DSC barriers and DSC strategies. The result shows that "absence of urgency for SC digitalization", lack of proper innovation strategies", and "Inadequate leadership to lead digital transformation "are the highest-ranked DSC barriers that needs to be overcome on a priority basis, and "determined top management commitment to digitalization to gain a competitive edge", "planning and coordination for implementing digital technologies in SC", and "Adequate management of investment for comprehensive digitalized business" are the top-ranked DSC strategies which has to be considered on priority basis by the management to overcome most of the barriers. Accordingly, the management should effectively plan to mitigate the DSC barriers and implement strategies phase-wise for successful DSC implementation. This study will also guide the practitioner to select the optimal strategies within the available resources. Sensitivity analysis has also been done for the obtained results, whose analysis shows that the proposed research model is robust as ranking strategies are relatively sensitive to barrier weights.

1. Introduction

Supply chain (SC) managers are under enormous pressure because of the growing influence of the corporate world and the internet on consumer purchasing behaviour and demand patterns [1]. Therefore, it is imperative that SC managers prioritize the enabling new processes, boosting corporate connectivity, and expanding business agility [2]. Over the past decade, the proliferation of social media platforms and smart connected devices has dramatically altered consumers' reaction time and multi-channel service expectations [3–5]. Technology, especially the Internet of Things (IoT) and information and communication technologies (ICTs) [6], has had a profound effect on the manufacturing setup of any typical organization, and the SC is just one functional area that has been profoundly altered as a result [7,8]. Digital transformation is critical for modern firms due to innovation acceleration in businesses. Customer service, supplier relationships, sales, and company growth all benefit from digital transformation [5]. According to Saarikko et al. [9] The use of advanced digital tools and technology to modify and improve business practices, policies, corporate cultures, and customer experiences to meet shifting business demands is known as "digital transformation". Digital transformation can help businesses identify consumer preferences, strengthen customer connections, acquire real-time visibility into processes, and create a more agile SC [10]. It also facilitates the expansion of production, product availability, pricing, and delivery schedules, as well as, most notably, sustainable development [11]. Digitizing the SC has many benefits for businesses in all sectors, but it entails operational and financial factors that can hinder long-term performance [12]. However, SC digitization faces some obstacles which would require cautious solutions [13]. The gradual adoption of digitalization across SCs may have two key impacts; firstly, there are a variety of roadblocks that prevent companies from deploying digitization strategies throughout the entire SC. Second, some of the enabling components may prove useful in the future for the SC and for enterprises as they make the move to digital technology. Due to the low rate of digital technology

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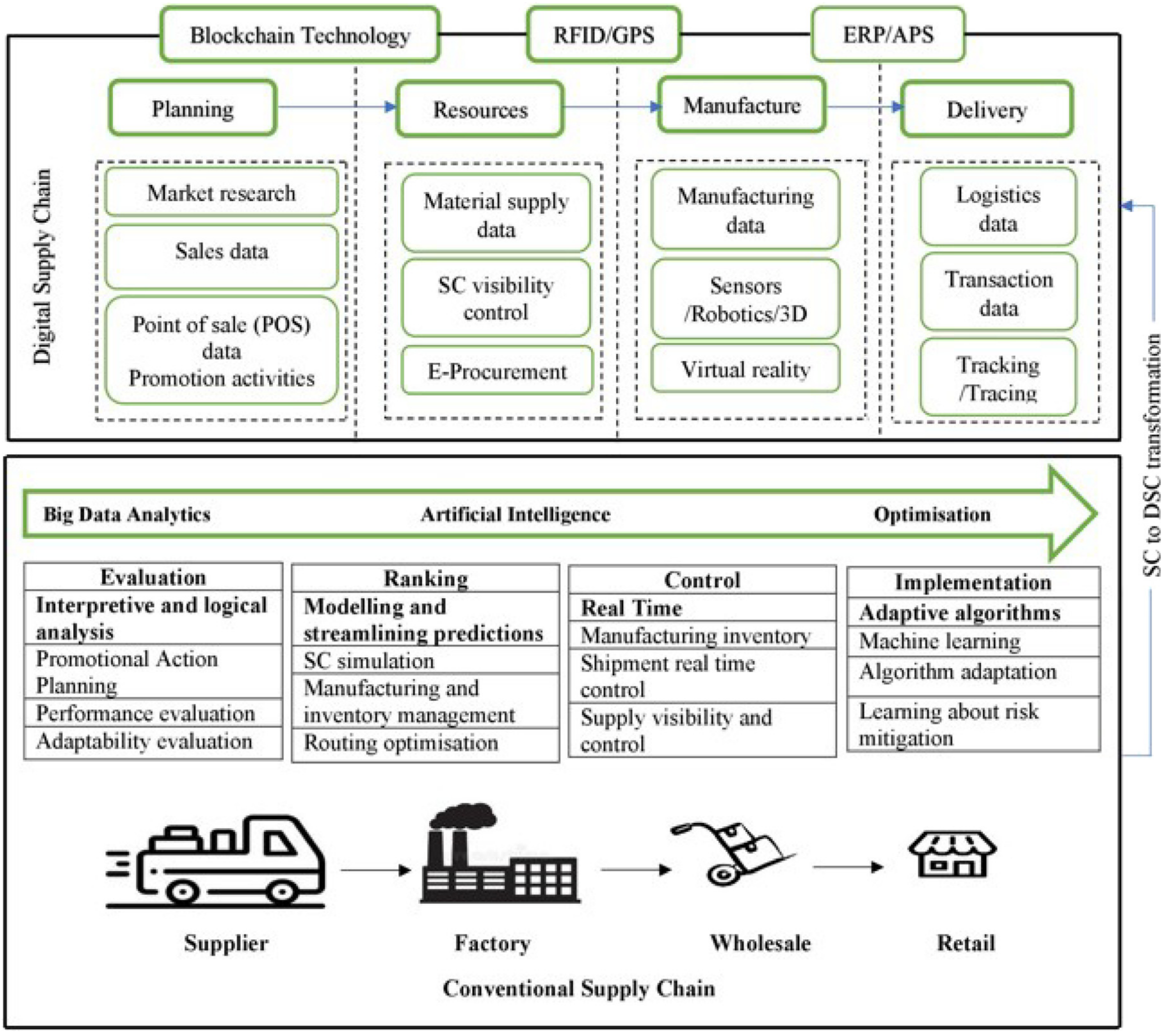

Fig. 1. Conventional SC to DSC transformation [26].

adoption, SC managers need to be aware of both the challenges that come with digitization and the opportunities it presents [14,15]. For the effective digital transformation of the SC, the organization must create the necessary innovative environment to enable effective action, performance, and continuous progress to maintain the necessary enthusiasm and confidence amongst the employees [16,17]. Digitization is still an emerging phenomenon that requires more administrative insight than theoretical comprehension [18]. The term “digitalization” refers to a modern business strategy that goes beyond the single and limited application of technology to include SC wide systematic implementation [19,20]. The automotive industry is now affected by the disruptive effects of digitization, which is the most significant development in recent years. There were many different factors that have an increasing amount of influence on the automotive industry [21–24]. These include consumer and product diversification, globalization, which enables manufacturers to enter new markets and a shorter product lifecycle in order to keep up with the rapidly changing demands of consumers with innovative products [25].

The implementation of digital technologies in the field of supply chain management (SCM) would result in the adoption of SC practices that are more efficient, agile, and lean. In order to attain more competitive advantage, digitalizing the SC is fundamentally essential. This is because, in today’s competitive environment, it is not the enterprises that are competing with one another, but rather their supply chains (SCs). Therefore, digital supply chain (DSC) is one such concept that is gaining the utmost attention for effective SC activities. Recently, more focus has been placed on comprehending how demographic factors impact DSC approaches [27]. Even though many studies have focused on technological adoption, there were several research that shows how DSC evolved from classic SC to DSC. Fig. 1 shows the transformation of conventional SC to DSC. SC digitalization requires the internet of things (IoT), big data analytics (BDA), robotics, autonomous guided vehicles (AGVs), and other technologies. Organizational digitization requires careful planning to implement digital technologies [28]. The expertise gained from experienced business tycoons around the world is vital to the DSC’s growth [29]. ICTs improve buyer–seller relationships by encouraging openness and basic information sharing. Digital knowledge exchange may modify firms’ structures, affecting decision-makers’ preferences and willingness to adopt new technology [30]. According to Büyüközkan and Göçer [4] and Ageron et al. [13], DSC is an intelligent technology platform for digital networks that relies on effective communication to facilitate and synchronize business-to-business interactions by increasing value, accessibility, and cost-effectiveness with consistent, rapid, and efficient outcomes. Both Sun et al. [31] and Frederico et al. [32] note that the notion of DSC has emerged as a result of the emergence/impact of ICTs and IoT based on cyber–physical system architecture in production, logistics, and SC application area. Further, the DSC can be outfitted with machine-generated data and can support linking several SC partner tiers and combining product/service components for analysis of evolving business settings [33]). There is a significant research opportunity to understand the DSC concept as well as to identify motivating factors, drivers, and barriers to DSC adoption because the research in this field is still in its early stages [32,34]. Many researchers, such as Agrawal et al. [5], Zekhnini et al. [35], and Annosi et al. [36], have only attempted to evaluate the implementation challenges and barriers associated with DSC. Also, Agrawal et al. [37] and Sharma et al. [38] identified different barriers/challenges along with drivers and enablers through literature review and proposed a framework to clarify the relationship between disruptive digital technologies and circular economy performance in SC. Additionally some researcher also identified different barriers and enablers [5,13,27,39–44]. These researchers identified and analysed DSC barriers, obstacles, and challenges, but they did not discuss, prioritize, or analyse DSC solutions or strategies. According to Ageron et al. [13], expanding the theoretical scope of DSC by adopting it to organizational strategy, studying new digital skills, and offering project management techniques is crucial. Digital technologies could be better integrated into the DSC framework, leading to improved DSC performance. In contrast to earlier research, the current study not only identifies and evaluates the obstacles that stand in the way of DSC, but it also identifies and ranks the strategies that can be used to overcome these barriers and obstacles.

The goal of this study is to identify barriers and strategies to DSC adoption in automobile organizations. Based on the study objectives listed above, the following research questions (RQ) can be developed:

RQ1*: What are the major barriers to DSC adoption in an organization*?

RQ2*: What are the most preferable strategies to mitigate the effect of these barriers?*

RQ3*: How can these identified DSC adoption barriers and mitigation strategies be evaluated and prioritized?*

To address the above-mentioned research problems, the following Research Objectives (RO) have been developed:

RO1*: To determine the main barriers in DSC adoption.*

RO2*: To identify and provide the most preferable strategies.to mitigate barriers to DSC implementation.*

RO3*: To achieve the most prevalent strategy that minimizes the effect of the most significant impediments to implementing DSC. Also proposed a framework of DSC implementation and to check the robustness of framework*.

To achieve these objectives, this study aims analyse the barriers to DSC implementation, identify the strategies/solutions to overcome these barriers, and offer a framework to mitigate these constraints. This study demonstrates the complex interplay between the various sets of barriers and strategies, and the Multiple Criteria Decision Making (MCDM) methods has been employed to rank the different set of DSC strategies. A framework that considers both the modified stepwise weight assessment ratio analysis (SWARA) and the combination compromise solution (CoCoSo) approach has been proposed through three-stage. In the first stage, twenty-five barriers associated with DSC were found, along with seventeen possible strategies to mitigate the impact of these barriers. In the second stage, the modified SWARA method was used to assess the weight of finalized DSC barriers because of its ability to address decision-making problems in a timely and efficient manner. In the final stage, the CoCoSo technique has been utilized to rate the strategies in relation to predetermined barriers of DSC.

Many authors have utilized MCDM approaches for DSC implementation, such as partial least squares structural equation modelling (PLS-SEM) [45], analytical hierarchy process (AHP) and Decision-making trial and evaluation laboratory (DEMATEL) [39], Interpretive structural modelling (ISM) and MICMAC [5,40]. Pythagorean fuzzy analytic hierarchy process (PF-AHP) and Pythagorean fuzzy-evaluation based on distance from average solution (PF-EDAS) [41], Bayesian best–worst method [46], fuzzy best–worst method (FBWM) and modified Total Interpretive Structure Model (m-TISM) [47], fuzzy analytic hierarchy process (F-AHP) [48], Fuzzy-Decision-Making Trial and Evaluation Laboratory approach [49] etc. Other comparable MCDM approaches, such as Measurement of Alternatives and Ranking according to the Compromise Solution (MARCOS), have certain shortcomings, such as the inability to handle qualitative criteria [50]. The Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval (RAFSI) approach employs complicated mathematical equations that are difficult to comprehend [51]. The VIKOR (VIekriterijumsko KOmpromisno Rangiranje) approach is vulnerable to rank reversal [52]. MultiAtributive Ideal-Real Comparative Analysis (MAIRCA) is a strong mathematical tool and technique to problem solving that may be coupled with others. Quantitative assessments, on the other hand, are inadequate for characterizing individual ideas and perspectives and cannot fully represent the vagueness and ambiguity of experts [53]. The Level Based Weight Assessment (LBWA) approach is incapable of dealing with ambiguity and is not suitable for group decision-making [54]. The Full Consistency Method (FUCOM) approach has limitations in terms of research available to verify the study [55]. However, these approaches need more data and do not consider the link between each criterion to find and assess the normalized weight for each evaluation criteria. The SWARA and CoCoSo methodologies are used in place of other MCDM methods because SWARA has several benefits over other methods such as it deals with the capacity to determine experts' opinions about the significance of the criteria in the process of weight analysis. Also, it is useful for coordinating and gathering data from experts because it is straightforward, intuitive, and easy to understand by experts and it takes into account priority of challenges according to organizational regulations [56]. The CoCoSo technique improves the accuracy of the decision-making system by harmonizing business rules, which results in beneficial outcomes for management supervision. CoCoSo method allows decision makers to achieve a multidimensional compromise solution compatible with modifying the weight of criteria. The CoCoSo technique provides benefits in terms of decision-making precision and consistency [57,58]. Therefore, modified SWARA and CoCoSo have been used to fulfil objectives of this research. A case study of an Indian automobile organization has also been conducted to check the applicability of the framework. For effective management of DSC implementation, the proposed framework provides accurate, clear understanding about the barriers and strategies of DSC.

The rest of the paper is organized as follows: Section 2 examines the literature on DSC implementation barriers and strategies, and at the end of this section research gaps have been stated. Section 3 discusses the research methods used in this study. Section 4 highlights the research framework used to achieve the goal of this paper. Section 5 presented the findings' results, discussion, and sensitivity analysis. Section 6 discusses the implications of this research. Finally, Section 7 addressed the conclusion/observation, limitations, and future research directions.

2. Literature review

2.1. Review of literature for DSC barriers

The potential benefits and limitations of the DSC are rarely addressed in a clear manner in current research practices [35]. As a result, more in-depth research is needed to better understand the main challenges and approaches to implement DSC [59]. There could be numerous issues with the implementation of DSC. According to Xu [60], the primary challenge in developing a DSC is acquiring critical data from multiple sources, ensuring credibility, and developing a platform that can use the data to manage and carry out SC activities. Data has become a valuable strategic asset for businesses because of the internet's proliferation and subsequent improvements in data storage, transmission, and retrieval speeds [61]. As a result, it is critical to design digital SCs to accommodate the new information-driven manufacturing environment in which product information travels autonomously at internet speed [62].

Recent technological advances are expected to have long-term consequences for entire SCs that are globally connected [63]. External relationships and conflicts between firms are two of the most significant challenges associated with DSCs ([64]; Rabetino et al., 2021; [65,66, 66]). Firms can meet these challenges with the help of digital technologies, which promote the recognition of inter-organizational logic, better SC management, and the restructuring of inter-organizational processes [67,68]. Thus, investigating the impact of digital technologies on SCs is critical [64,69]. In recent years, there has been a significant increase in research on DSCs and their implications, providing many valuable insights while fragmenting the literature and blurring the distinctions between what we know and what we do not know [4,70]. Existing research demonstrates tendencies that hinders the development of a thorough and balanced knowledge. Many studies emphasize on potential benefits of DSC adoption while disregarding challenges and critical success factors (e.g., [66,71,72]). Even though DSC encompasses a wide variety of technologies, there is a common tendency to explore only a subset of them in each research study [73].

A thorough review of the literature has been conducted to identify research articles that addresses barriers/obstacles, issues, and failure factors of DSC implementation (see Table 1). Agrawal and Narain [74] and Sharma et al. [38] identified many barriers/difficulties, as well enablers, and developed a framework to elucidate the link between disruptive digital technologies and circular economy (CE) performance in SC . They concluded that digitally enabled CE practices assist to enhance a variety of performance measures (i.e., resource optimization, waste reduction, product life cycle, occupational health, social performance, product safety and quality, and customer loyalty and satisfaction etc.). TS and Ravi [40] identified and analysed the interrelationships between the main challenges impacting Supply chain digitalization. Lahane et al. [41] identified and analysed different challenges/barriers of Industry 4.0 adoption in sustainable food supply chain using hybrid Pythagorean fuzzy analytic hierarchy process (PF-AHP) and Pythagorean fuzzy-evaluation based on distance from average solution (PF-EDAS).the results revealed that top management's poor perception of digitization and lack of willingness to adopt an Industry 4.0 enabled sustainable food supply chain are the most critical barriers, whereas top management commitment and support is the most important solution. Singh and Maheswaran [75] analysed societal impediments to sustainable and digitalization of supply chain using best–worst method (BWM) and decision-making trial and evaluation laboratory (DEMATEL) methods. The findings indicated that "work-related circumstances" and "employment disruptions" are most critical social barriers. Weerabahu et al. [76] conducted a content analysis of systematic literature and identified four broad categories of DSC facilitators and barriers their findings indicated that adoption of the DSC was suffered by a lack of infrastructure and financial constraints. Agrawal et al. [5] to identify the twelve barriers with most influencing barriers such as lack of industry-specific norms, lack of digital skills and expertise, expensive installation and running cost etc. to a firm's DSC transformation using ISM-MICMAC technique. Sahebi et al. [59] investigated the barriers to blockchain adoption in humanitarian SC by exploring the obstacles such as legislative ambiguity, a lack of understanding, insufficient personnel training, and high sustainability costs to blockchain deployment in the context of humanitarian SC management and logistics by using a hybrid methodology that combined the Fuzzy Delphi and the Best-Worst method. Annosi et al. [36] highlighted food SC digitization and identified various barriers and drivers by providing insight into how business operations and SC architecture have been re-envisioned using digital technology. Bag et al. [49] examined fifteen obstacles to the use of blockchain technology in green SC management and discovered the two most significant impediments as lack of management vision and cultural differences among SC partners. Kache [77] used the Delphi method to identify and analyse forty-three challenges and opportunities related to the introduction of BDA from a corporate and SC perspective. Büyüközkan and Göçer [4] identified and stated several challenges of DSC implementation such as lack of planning, lack of collaboration, wrong demand forecast, lack of information sharing, silver bullet chase, lack of knowledge, agility and flexibility, high volatility, overconfidence in suppliers, and lack of integration. A thorough and comprehensive literature review has been conducted to identify various DSCBs for the organizations. These obtained DSCBs are then further classified into five subsections and explained (see Table 1) below:

2.2. Review of literature for strategies of DSC implementation

In recent years, the digitalization process, aided by ICTs [143,144], has been a critical factor in firms gaining a competitive advantage [145]. This is due to the adoption of digital technology, which can be accomplished by introducing new business models [146,147]. Retail, steel production, food packaging, manufacturing, and construction are among the industries that have begun business digitalization procedures [148]. Manufacturing firms can use digital technologies to adopt, design, and deliver new smart and connected products that will alter competition and on-time service delivery [64,149]. As a result, enterprises have been entrusted with developing a set of DSC strategies to gradually aid the digitalization process and alleviate the hurdles [150]. Several authors, including Saberi et al. [135],Attaran and Attaran [151],Xing et al. [152],Averian [153], and Ngo et al. [45], stress the importance of creating a digitalized ecosystem for various SC partners by encouraging an open culture of collaboration and innovation, fostering mutually beneficial relationships, institutionalizing agile management practices, and funding the appropriate digital technologies. Adequate investment management is required for a comprehensive digitalized business [10,154–156], which is an important metric for determining an organization's readiness to establish a digitalized SC ecosystem. Talent development among existing workforce for digitalization overcomes barriers such as a lack of awareness among workforce and stakeholders about digital means, a lack of digital capabilities among existing employees, and a lack of infrastructure for training programmes to reskill or upskill the workforce for digitization [157–159]. Adequate government digitalization policies can encourage businesses and SCs to digitally transform [160]. Organizational flexibility and new technology adoption in SC stimulate the creation of new positions within the organization because new technologies necessitate different skills and obligations from employees (Bruque & Moyano, 2007; [161]). Quality and customization results require the integration of SC processes throughout the organization such as vertical integration is the most advantageous growth strategy because it involves merging businesses that serve the same clients but offer different but complementary products or services [76,162,163]. Horizontal integration is the process of growing a business by introducing new skills and knowledge into an industry in order to reduce production costs and improve response time when competing with emerging markets [163, 164]. Almost 40% of businesses employ big data analytics, and 90% of internet users prefer to purchase products online [13,165]. Adopting DSC solutions/strategies appears to provide businesses with both a competitive advantage and long-term value. Digitization has also had a significant impact on SC processes. In a March 2016 report, Capgemini pvt. ltd. proposed a five-year plan for implementing a systemic DSC strategy. The DSC five-year plan includes three level factors: User Value Factors, top business drivers, and performance-based SC management [13,166,167].

The adoption of digital transformation (Industry 4.0) can improve the information sharing and decision-making process [168]. Early SC digitization (SC-4.0) implementation can give the organization a competitive edge [169,170]. Predictive analytics (PA) and big data (BD) are examples of advanced technologies that can improve organizational performance by increasing visibility, robustness, and resilience [2]. The use of cloud computing within the SC has received little attention in theory and practice, few empirical studies have concentrated on the factors influencing cloud computing adoption [171,172] and the impact of cloud computing on the SC [173,174]. SC transformation can be accelerated by number of factors, including product/process optimization, inventory management, supplier collaboration, operational excellence,

Table 1
List of barriers of DSC extracted through literature review.

Criteria	Code	Factors	References	Description
Strategic barriers	SB1	The inadequate strategic focus on digitalization	[78–80]	Digital efforts may become disorganized and fail to produce the expected results if they lack a clear vision and plan Organizations must establish their digital transformation objectives and build a roadmap outlining the measures necessary to accomplish them.
	SB2	Lack of proper innovation strategies	[46,81,82]	Proper innovation strategies are critical for the organization to adopt DSC. A certain sort of business system supports specific types of innovation strategies. Similarly, ensuring strategic alignment between company goals and technical efforts is critical to the success of any digital effort.
	SB3	Absence of urgency for supply chain digitalization	[5,35,83,84]	One of the major challenges to DSC adoption is a lack of urgency in digitalization. The sudden and heightened urgency of digital transformation is felt by all organizations. However, there is still confusion about what digital transformation entails.
	SB4	Lacking industry-specific rules for digitalization	[5,85,86]	Digital technologies provide significant challenges to the way governments regulate, by distorting the conventional definition of markets, complicating enforcement, and crossing administrative borders both locally and globally.
	SB5	Lack of R&D facilities and capabilities	[87–89]	Successful innovation is dependent on an organization's combination of capabilities such as financial capability or access to finance, hiring highly skilled personnel, market knowledge, research, and development (R&D), and establishing effective collaboration and cooperation with other supply chain partners
Organizational barriers	OB1	Inadequate organizational structure	[46,79]: [90]	The organization structure plays critical role in digital transformation. The primary challenge for leaders and managers is to create and maintain an organizational structure that is adaptable, flexible, receptive, accessible, and inventive.
	OB2	Inadequate performance appraisal system	[91,92]	An inadequate mechanism for performance evaluation causes unhappy employees.
	OB3	Lack of understanding of the dimension of the digital business environment	[93–95]	A business environment with a high adoption rate of digital technology helps organizations to operate with a reduced regulatory burden. When competitive pressure, job security, and product market laws are clear and flexible, the relationship between superior managerial quality and a higher rate of digital adoption is recognized.
	OB4	Lack of top management support and commitment	[96–98]	Top management support and commitment implies that managers are active throughout the development and deployment process and completely support innovative efforts.
	OB5	Inadequate knowledge of acquiring data from several sources and their credibility	[60]	The primary challenge in developing a DSC is acquiring critical data from multiple sources, ensuring credibility, and developing a platform that can use the data to manage and carry out SC activities.
Technological barriers	TB1	Lack of awareness among workforce and stakeholders about digital means	[99–101]	Understanding how basic technology works, as well as how to utilize its many tools and gadgets properly, is critical in digital transformation. It is a crucial part of life in today's tech-dominated culture, and it provides us with several opportunities for growth and success.
	TB2	Inadequate digital capabilities among the existing employees	[102–105]	The absence of digital abilities renders it much more difficult to employees in contemporary professions to carry out with their everyday tasks but employees with digital abilities might find it difficult to maintain pace with an inflow of trends and technology.
	TB3	Concerns about data security and privacy	[4,106–108]	Data security and privacy is the major concern in the digital age since data might be leaked or transmitted to rivals or third parties.
	TB4	Inadequate infrastructure for conducting training programs to reskill or upskill the workforce in preparation for digitization	[109–111]	According to the World Economic Forum, by 2025, 50% of all workers will need reskilling owing to the use of new technologies. Over two-thirds of the abilities deemed crucial in today's employment requirements will change in five years. A third of the required abilities in 2025 will include technological talents that are not yet considered critical to today's employment needs [111].
	TB5	Inadequate cybersecurity safeguards to prevent data discrepancies	[112,113]	Cybersecurity is the activity of preventing unauthorized access and damage to computer systems, sensitive data, and networks. These cyber assaults are designed to steal information, alter internal data, or destroy sensitive data.

(*continued on next page*)

logistics/sales optimization, and after-sales service [13]. Additionally, DSC supports sustainable SC business practices that consider economic, social, and environmental factors [13,175]. Technology advancements in logistics and SC management have been facilitated by the blockchain technology. This technology has the potential to increase transparency and security, which is essential for managing complex SCs effectively ([176]; Bai and Sarkis, 2020). The transformation of conventional SC to DSC requires planning and coordination. DSC can make it simple to gather high-quality, current data as well as analyse, integrate, and interpret it [95,177,178]. Strategies to overcome the barriers of DSC implementation has been presented in Table 2.

2.3. Research gaps extracted through existing literature

Through an extensive literature review, no research study has been found that has conducted research to identify the various strategies to overcome the challenges for successful DSC implementation. Even though few researchers have highlighted the barriers/obstacles/ challenges of DSC implementation as mentioned in above sections (i.e., 2.1 and 2.2). Some of the key research studies have been identified that have examined the problems and challenges of DSC implementation such as Weerabahu et al. [76] proposed the digital supply chain maturity (DSCM) model that provides a thorough examination of the barriers/enablers and levels of adoption maturity from traditional

Table 1 (*continued*).

Criteria	Code	Factors	References	Description
Financial barriers	FB1	Uncertainty over the return on investments put in emerging technologies	[114–116]	Organization should have adequate financial resources for digitization. Although organizations with funding are concerned about the uncertainty of the return on investment in new technologies adoption.
	FB2	Inadequate knowledge in understanding the value of investment in digital infrastructure	[117–119]	The term “digital infrastructure” refers to all electronic and non-electronic assets used to offer internet services to consumers. Investment in universal digital infrastructure is critical for Internet usage and is a crucial component of Sustainable Development Goals. The accessibility of broadband connectivity may open new economic options for previously disconnected populations and contribute to larger structural changes in labour markets towards more productive, digitally enabled industries.
	FB3	High costs of digital tools, setting up equipment, and implementation	[120–122];	SC digitization necessitates a larger initial investment [120]. As financial barriers are major obstacle to DSC implementation because of the high expenses of digital tools, setting up equipment, and execution
	FB4	Lack of long-term economic and financial policies	[46,123–125]	Financial policies define the roles, duties, and authority for critical financial management tasks and decisions. Staff and board members are likely to work on a set of assumptions that may or may not be true or productive in the absence of an accepted policy. The organization is hesitant to undertake SC digital transformation because they lack in long-term economic and financial plans.
Leadership barriers	LB1	Lack of team commitment and a hostile working environment	[125–127]	Leaders who lack skilled workforce cannot push staff to perform effectively. Team commitment and a hostile working environment is essential for improved performance and job satisfaction.
	LB2	Inadequate leadership to lead digital transformation	[128–131]	The role of leadership is very critical while adopting digital transformation. Leaders are individuals who can influence and encourage their people to work efficiently [132]. Due to insufficient leadership to lead digital transformation the organizations may fail to achieve digital transformation.
	LB3	Lack of governance mechanism adoption	[133]	Leaders today may demonstrate great integrity by using the linked nature of technology and being more honest about their vision and values. When the consortium expands governance will be a challenge for leaders. A specialized team will be tasked which can developed a governance framework that specifies participation and determining rights
	LB4	Management’s lack of trust in sharing critical information and technologies among various actors	[134–136]	Top management’s lack of trust in sharing critical information and technologies among various actors may hinders the employee’s involvement for digitization of SC.
	LB5	Lack of trust of management towards employees and middleman	[137–139]	The major factor that may cause a sick workplace culture is a lack of trust of management towards employees. It often starts with the leader and extends across the team, resulting in a loop of unhealthy reactions that impact engagement and productivity. Employees will complete the task assigned to them, but without faith in their leaders, they are unlikely to go farther than necessary to contribute to great performance.
	LB6	Fear of reduction in human involvement in adopting digital solutions	[140–142]	Employment issue primarily include the competencies required for digitization, the human side of job replacing for robots and machines, and reluctance to change owing to a persistent attitude. Concern about robots overtaking people, as well as emerging relationships. The existing attitude, the requirement for adaptability, and the redesign of procedures and methodologies are all barriers.

SC to DSC. However, it integrates practitioner suggestions that the DSCM model be further simplified and experimentally proven. Agrawal et al. [5] identified and prioritized the many impediments to the SC's digital transformation framework. In preparation for planned initiatives and practical studies on DSC hurdles/barriers, Ageron et al. [13] highlighted the problems and provided a shared theoretical framework for the DSC. Queiroz et al. [215] develop a framework that illuminates DSC challenges and capabilities and presents a thorough understanding of DSC complexities, allowing scholars to reconsider the need for organizations to create new business models to comprehend, develop, monitor, and control these new capabilities that incorporate cutting-edge technologies.

Previous studies including, [4,13,27,38,74,74], primarily focused on the drivers or barriers of the DSC adoption. Majeed and Rupasinghe [216] and Ben-Daya et al. [217] investigated importance of IoT for Industry 4.0 and DSC by enabling SC planning and coordination processes. Kache [77] address the intersection of SCM and Big Data Analytics in an exploratory Delphi method that shows some potential obstacles and difficulties associated with the emergence of Big Data analytics from both a business and a SC standpoint. Annosi et al. [36] conducted a qualitative study based on expert interviews to identify obstacles linked with food SC digitalization. Bag et al. [49] used the Fuzzy-DEMATEL technique to identify cause-and-effect correlations and prioritize the hurdles to blockchain adoption in green SC management. Büyüközkan and Göçer [4] conducted a thorough assessment of the literature and identified the challenges of DSC implementation. However, no such study has yet been identified that clearly addressed DSC barriers and strategies for overcoming DSC barriers. Hence, this study prioritizes the strategies to overcome the barriers to DSC implementation which are shown in subsequent sections.

3. Research methodology

To accomplish the research objective of the study, MCDM methodology-based hybrid modified SWARA and CoCoSo framework has been developed. The SWARA method is used to calculate the weights of the DSCBs, and the CoCoSo method is used to prioritize the strategies to overcome the barriers to DSC implementation. In the past, researchers used SWARA and CoCoSo methods in conjunction to analyse a specific application area relevant to their study. For instance, Bai et al. [218] used an integrated MCDM approach called q-rung orthopair fuzzy sets (q-ROFSs), SWARA, and CoCoSo to investigate sustainable circular SC risks in the manufacturing industry. Kumar et al. [219] used an integrated methodological approach based on SWARA and CoCoSo methods to find the best spray-painting robot for the automotive industry. Cui et al. [220] used Pythagorean fuzzy SWARA and CoCoSo methodologies to assess the major barriers to IoT implementation in the manufacturing sector within the context

Table 2
Strategies to overcome the barriers of DSC implementation.

Sr.No.	Abbreviation	Strategies	References
1	S1	Developing a digitalized ecosystem for various supply chain partners	[135,151,179]
2	S2	Adequate management of investment for comprehensive digitalized business	[154–156,180]
3	S3	End to end Integration (horizontal/Vertical) of SC processes for better results of digitization and customization	[163,181,182]
4	S4	Developing an effective strategic alliance for collaborative scope	[79,183,184]
5	S5	Determined top management commitment for digitalization to gain the competitive edge	[158,159,185]
6	S6	Development of talent among the existing workforce for digitalization	[157]; [158,159]
7	S7	Adoption of governmental policies and regulations related to digitization in SC	[76,125,186,187]
8	S8	Organizational flexibility and adaptability of new technology in SC	[161,188,189]
9	S9	Planning and coordination for implementing digital technologies in SC	[26,190,191]
10	S10	Awareness to build knowledge related to SC digitalization among existing employees	[192–194]
11	S11	Standardization of IT-enabled services for efficient integration of technologies	[195–197]
12	S12	Promoting an innovative culture among the workforce for better results of digitization	[124,198,199]
13	S13	Preparing the workforce through adequate training for managing digital activities in SC	[99,200,201]
14	S14	Adoption of new digital technologies for real-time product tracking	[27,202,203]
15	S15	Development of a proper network security system to prevent data privacy	[204–206]
16	S16	Adoption of digital transformation and automation for rich user experience	[207–210]
17	S17	Evaluating the value proposition for digital products and services	[211–214]

of a circular economy. Ulutaş et al. [221] used fuzzy SWARA and CoCoSo to solve the location selection problem for a logistics centre. Wen et al. [222] conducted an analysis for the selection of drug cold chain logistics suppliers using the SWARA and CoCoSo methods in a probabilistic linguistic environment.

Although no research combining SWARA, and CoCoSo in the area of DSC implementation has been found. Therefore, this study proposes a hybrid modified SWARA and CoCoSo framework for overcoming DSC barriers. The modified SWARA method has been used to calculate the weight of the barriers to the DSC adoption and CoCoSo has been used to prioritize the strategies as per the weight obtained from the modified SWARA method.

3.1. Modified stepwise weight assessment ratio analysis (SWARA) method

SWARA is a multi-criteria decision-making (MCDM) approach that was developed by Kersuliene et al., (2010) to assess and solve decision-making problems quickly and efficiently. In this approach, the expert plays a vital role in evaluating and weighing the criteria. Experts shall initiate the SWARA technique by arranging the criteria in descending order of expected importance. The most important criteria will be assigned the highest significant value, and the least important criterion was assigned the lowest significant value among all the criteria [223]. SWARA is thus recognized as a potential decision-making instrument for complex problems with multiple criteria. This method has been used by different researchers with wide range of applications. Some recent studies used SWARA method includes analysis and ranking of sustainable human resource management factors [224], food waste treatment technology selection [225], global retail SCs [226], analysis of risks in coal SC management [227], analysis of barriers of Industry 4.0 implementation [223], analysis of barriers of reverse logistics implementation [228]. the design of products [229], research and development project selection [230], legislative tasks (Kersuliene et al., 2010), hospital construction project [231] etc. The various steps of the SWARA method are as follows-

Step 1. Define the relevant criteria in the decision problem and ranking them from best to worst based on the experts' expertise and knowledge. C_j $(j = 1, 2, \dots, n)$ denotes these criteria, where C_1 and C_n represent the best and worst criteria, sorted by their assigned ranks.

Step 2. In this step, calculate the average value of comparative importance (S_j) of each criterion based on the corresponding rank. S_j explains why criterion C_j is more significant than criterion $C_j + 1$.

Step 3. In this step, obtain the coefficient K_j using the Eq. (1)

$$K_j = 1, \quad \text{if } j = 1$$
$$K_j = S_j + 1, \quad \text{if } j > 1 \tag{1}$$

Step 4. In this step, determine the recalculated weight (q_j) for the considered criteria using the below equation.

$$q_j = 1 \quad \text{if } j = 1$$
$$q_j = \frac{q_{(j-1)}}{K_j}, \quad \text{if } j > 1 \tag{2}$$

Step 5. In this step, calculate the relative weight (W_j) of each criterion

(using Eq. (3)) by dividing the recalculated weight (q_j) obtained in step 4 by the sum of the weights. The value of relative weight was calculated using the equation.

$$W_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{3}$$

Step 6. In this step, calculate the global weights of the criteria by multiplying the relative weights of the main criterion with the relative weights of the corresponding sub-criteria.

3.2. Combined compromised solution (CoCoSo) method

Yazdani et al. [232] proposed CoCoSo, a novel and effective MCDM approach. The CoCoSo method combine strategies based on basic additive weighting and exponentially weighted product decision-making algorithms. It also enables the decision makers for obtaining a multidimensional compromise solution that is consistent with changing the weight of criteria. The CoCoSo method has advantages in terms of accuracy and consistency in decision-making output [57,58]. Considering many advantages, researchers have recently focused on using CoCoSo method for solving the complex decision-making problems includes analysis of health and safety risk [233], selection of the best engineering sustainability components [234], blockchain Platform Evaluation [235], assessment of risk [236], examining circular economy practices [237], autonomous vehicle prioritization in real-time traffic management [238], electric car evaluation [239], and manufacturing technology assessment [57]. The methodological steps of CoCoSo are as follows:

Step 1: Development of the initial decision matrix ($m \times n$) with the help of expert's opinion. For illustration, initial decision matrix has been shown in below equation.

$$D = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \quad \text{where, } (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n) \tag{4}$$

Step 2: Normalization of the initial decision-making matrix using the below equations.

For benefit criteria

$$rij = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{5}$$

For non-benefit/cost criteria

$$rij = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{6}$$

Step 3: Obtaining the sum of the weighted comparability sequence for each alternative using Eq. (7)

$$s_i = \sum_{j=1}^{n} w_j * r\prime \tag{7}$$

Step 4: Obtaining the total power weight of the comparability sequences for each alternative using equation as given below-

$$p_i = \sum_{j=1}^{n} (r\prime)^{w_j} \tag{8}$$

Step 5: Determining the relative weights of the alternatives using the Eqs. (9)–(11).

$$K_{ia} = \frac{p_i + s_i}{\sum_{i=1}^{m} p_i + s_i} \tag{9}$$

$$K_{ib} = \frac{s_i}{\min_i s_i} + \frac{p_i}{\min_i p_i} \tag{10}$$

$$K_{ic} = \frac{\lambda S_i + (1-\lambda) P_i}{\lambda \max_i S_i + (1-\lambda) \max_i P_i} 0 < \lambda < 1 \tag{11}$$

Where,

1. K_{ia} indicates the arithmetic mean of the scores from the weighted sum model (WSM) and the weighted product model (WPM).
2. K_{ib} indicates the total of the relative WSM, and WPM scores as compared to the best.
3. K_{ic} indicates the balanced compromise between the results of the WSM and WPM models

Step 6: Obtaining the assessment value, K_i using the Eq. (12).

$$K_i = \sqrt[3]{K_{ia} K_{ib} K_{ic}} + \frac{K_{ia} + K_{ib} + K_{ic}}{3} \tag{12}$$

Step 7: Obtain the rank of the criteria in decreasing order of K_i ($i = 1, 2 \ldots m$).

4. Proposed research framework

The proposed research framework has been divided into three phases for analysing the challenges/obstacles and strategies for DSC implementation. The first phase entails identifying and finalizing barriers/obstacles to DSC implementation, as well as strategies to overcome these barriers. The second phase includes an assessment of the weight of DSC barriers using the SWARA method. The third phase consists of ranking the DSC implementation strategies using the CoCoSo method. The proposed framework for analysing DSC barriers and strategies has been depicted in Fig. 2.

5. Application of proposed framework

5.1. Problem description and a brief overview of case company considered

The implementation of DSC and its functioning is becoming the core activity of many manufacturing organizations. Automobile organization is one of them because DSC implementation is highly relevant in the automotive sector. Though Indian automobile organizations have begun to implement and maintain DSC practices, but their effectiveness is very low due to the use of poor DSC strategies. To improve the success rate of DSC implementation, highly relevant and effective DSC strategies must be identified. There is a need for research in identifying important DSC strategies so that Indian automobile organizations can focus on these high-rank strategies before start to implement them. The proposed framework has been applied to a considered case company (i.e., 'A1'). The case company is associated in the production and supply of internal hydraulic power steering systems in India. A1 organization has more than 1000 employees with the annual turnover of more than 300 crores. The mission of the company A1 is to reach new heights of global recognition as a world-class power steering gear manufacturer through catering the ever-increasing needs of the power steering gear market for cars, trucks, and tractors.

In the present scenario, the company produces power steering for heavy commercial vehicles, light commercial vehicles, sport utility vehicles, tractors, and passenger cars. In addition, fast development of superior quality products with good customer service has enabled organization 'A1' to become an original equipment manufacturer (OEM) supplier to many car and tractor companies in India, Europe, and Asia. The case organization 'A1' is interested in implementing DSC because it faces buyer pressure as well as strict environmental regulations around the world. The organization 'A1' faces challenges from its competitors regarding the adoption of digitization in the SC. Therefore, the organization's top management shows commitment to digitizing the SC. This company is concerned to identify and prioritize the solution/strategies of the DSC to mitigate its barriers. The subsequent three phases show how organization A1 utilizes the proposed SWARA and CoCoSo framework methodology to select the best DSC strategy for successful DSC implementation.

5.1.1. Phase 1: Identification and finalization of DSC implementation barriers and strategies

This section highlights the procedure carried out to identify and finalize the barriers and strategies associated with DSC implementation. Initially, a total of 26 barriers and 20 strategies have been identified through extensive literature analysis on the DSC. To finalize both barriers and strategies a panel of four expert members i.e., 02 professionals from the case company and 02 from academia (i.e., EP1, EP2, EP3, and EP4) were formed and they were consulted to provide their opinion about the relevance of identified barriers and strategies for DSC implementation in Indian automobile industries. The expert from academia holds relevant research experience in the domain of SCM. The experts from case company were having adequate industrial experience in implementing digitalization practices in SC. They have wide SC experience and belong to the SC and logistics department.

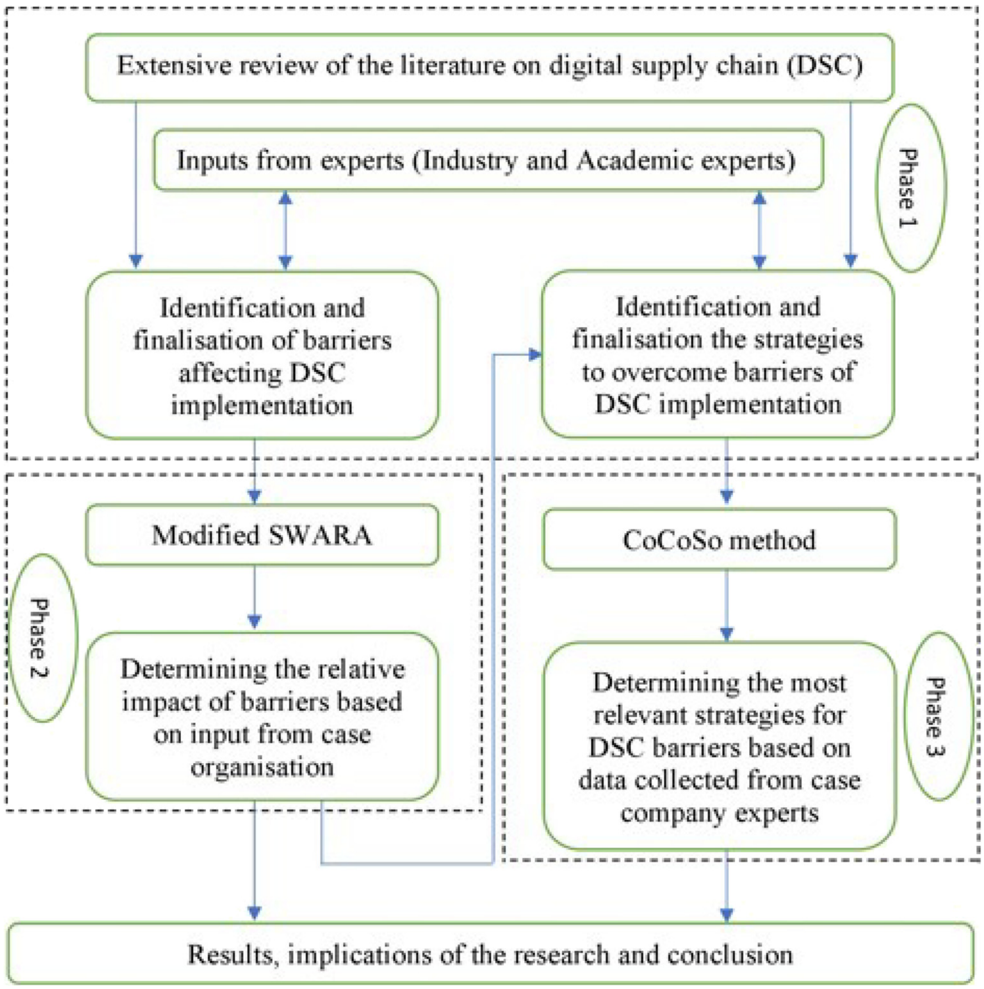

Fig. 2. Proposed research framework for prioritizing the strategies of DSCBs.

These professionals have been engaged in adopting digitalization practices in SC activities. Hence, it may be assumed that the knowledge of these personnel is sufficient for the research to be carried out. Upon discussion, 23 out of 26 barriers were finally selected. Later 2 more barriers were proposed by the case company experts extending the total to 25 barriers. Now, these finalized 25 barriers were categorized into five major categories namely strategic barriers (SB), organizational barriers (OB), technology barriers (TB), leadership barriers (LB), and financial barriers (FB). Table 1 provides a detailed list of 25 finalized barriers. Similarly, based on the discussion among the experts, three strategies have been removed by the experts from the list because, some of the strategies were found irrelevant and some were conveying the same meaning. Additionally, no new strategies have been suggested by the expert panel to the initial list. Hence, out of 20, 17 strategies were finally selected. The list of finalized strategies for DSC implementation can be found in Table 2.

5.1.2. Phase 2: Evaluating the relative impact of obstacles/barriers based on inputs from industry experts using the modified SWARA method

The modified SWARA methodological steps specified in Section 3.1 were performed to get the priority weights of DSCBs. As previously stated, a total of twenty-five DSCBs (sub-criteria) have been finalized and categorized into five major DSCB categories (main criteria). As a result, all calculations are performed in line with the major criterion and sub-criteria barriers. To begin the calculations, a questionnaire (refer to “Appendix A”, Table 6) was sent to obtain expert opinion on the relative importance of the average value for both the main criterion and the sub-criteria. The weights w_j for the main criteria DSCBs were then determined using a distinct set of values obtained from each of the four expert groups, EP1, EP2, EP3, and EP4. The geometric mean was used to aggregate the results collected. The relative weights of sub-criteria were also determined. “Appendix B” contains the computations for both the major criterion and the sub-criteria (see Tables 8 and 9). Step 6 (as described in Section 3.1) is used to calculate the overall weights of all sub-criteria, which are summarized in Table 3. According to Table 3, the Strategic Barrier (SB) has the greatest influence on DSC implementation, followed by the Leadership Barrier (LB), Organizational Barrier (TIB), Technology Barrier (LB), and Financial Barrier (FB) respectively.

5.1.3. Phase 3: Ranking the strategies/solutions for DSC implementation from the response received by the experts using the CoCoSo method

In this phase, the CoCoSo method has been used to rank the strategies of DSC implementation as per the weights obtained from the SWARA method. To proceed with the calculations associated with CoCoSo method, a questionnaire (refer to Appendix A, Table 7) was circulated among the expert panel for developing the decision matrix. The decision matrix has been developed by gathering the responses of the experts about the comparison of each DSCB in relation to each strategy. The response gathered from the different experts were aggregated using geometric mean. The steps of the CoCoSo methodology mentioned in Section 3.2. were used to obtain the final ranking of the strategies. Table 4 summarizes the final ranking of strategies obtained as per the descending order of Ki value. The details on the calculation of the final ranking of the DSC strategies have been shown in “Appendix C” (see Tables 10 to 14).

Table 3
The final ranking of DSC Implementation barriers.

Sr.N.	Main criteria	Relative weights	Sub criteria	Description	Global weights	Global rank
1	Strategic barriers (SB)	0.504378	SB1	Inadequate strategic roadmap for digitalization	0.078330	4
			SB2	Lack of proper innovation strategies	0.124833	2
			SB3	Absence of urgency for supply chain digitalization	0.230987	1
			SB4	Lacking industry-specific rules for digitalization	0.025944	11
			SB5	Lack of R&D facilities and capabilities	0.044264	7
2	Organizational barriers (OB)	0.12806	OB1	Inadequate organizational structure	0.005179	23
			OB2	Inadequate performance appraisal system	0.032466	10
			OB3	Lack of understanding the dimension of the digital business environment	0.009150	19
			OB4	Lack of top mgmt. support and commitment	0.064368	5
			OB5	Inadequate knowledge of acquiring data from several sources and their credibility	0.016902	15
3	Technological Barriers (TB)	0.14427	TB1	Lack of awareness among workforce and stakeholders about digital means	0.002989	25
			TB2	Inadequate digital capabilities among the existing employees	0.035393	8
			TB3	Concerns about data security and privacy	0.005293	22
			TB4	Inadequate infrastructure for conducting training programmes to reskill or upskill the workforce in preparation for digitization	0.019013	13
			TB5	Inadequate cybersecurity safeguards to prevent data discrepancies	0.010387	18
4	Financial barriers (FB)	0.08075	FB1	Uncertainty over the return on investments put in emerging technologies	0.011203	17
			FB2	Inadequate knowledge in understanding the value of investment in digital infrastructure	0.005913	21
			FB3	High costs of digital tools, setting up equipment, and implementation	0.021515	12
			FB4	Lack of long-term economic and financial policies	0.003297	24
5	Leadership barriers (LB)	0.252550	LB1	Lack of team commitment and a hostile working environment	0.011540	16
			LB2	Inadequate leadership to lead digital transformation	0.119729	3
			LB3	Lack of governance mechanism adoption	0.061431	6
			LB4	Management's lack of trust in sharing critical information and technologies among various actors	0.033656	9
			LB5	Lack of trust of management towards employees and middleman	0.018855	14
			LB6	Fear of reduction in human involvement in adopting digital solutions	0.007339	20

6. Result and discussion

This research thoroughly explains DSC implementation by outlining its strategies and challenges in descending order of importance. It is difficult to claim that DSC can be adopted in an enterprise environment without challenges. How these DSC barriers are managed will have a significant impact on an organization's ability to develop and adopt digital technologies. This study majorly focuses on to prioritize DSC strategies to effectively remove barriers to DSC adoption. According to the literature and expert opinion, a total of 25 DSCBs have been identified, as well as 17 strategies to mitigate all the DSCBs in a phased manner. An integrated modified SWARA and CoCoSo has been used, and detailed analysis was performed. The modified SWARA method is used to rank the most influential DSCBs, and CoCoSo is used to prioritize DSCB solutions as strategies. A case study has also been conducted in the Indian automobile industry to examine the applicability of the proposed framework. The findings for the weights of DSCBs are shown in Table 3. The results show that the "absence of urgency for SC digitalization" (SB3) received the highest priority weight (0.230) amongst the set of 25 DSCBS, as shown in Table 3. It is one of the major barriers to DSC adoption and this should be alleviated immediately. The digital transformation effort with SB3 must begin by installing and maintaining a sense of urgency with the organization [5]. Higher-level management plays a critical role in controlling SB3, and more focused attention is required to minimize SB3 for successful DSC implementation. Barriers such as "Lack of proper innovation strategies" (SB2) and "Inadequate leadership to lead digital transformation" (LB2) were ranked second and third, with priority weights of 0.125 and 0.119, respectively. Organizations must pay close attention to innovation strategies to succeed in capturing new markets, increasing market share, gaining a competitive edge, and adopting new technologies. Rapid technological advancements and intense market competition necessitate the implementation of effective innovation strategies, as any organization that fails to do so will not be able to remain competitive in the market [240]. The development of digital technologies has been the result of a global surge of innovation and disruption. These disruptive technologies have been found in a variety of areas, such as mobile phones, advanced robotics, and automated guided vehicles [241]. Management must be able to effectively communicate the motivations for

Table 4
Final ranking of DSC strategies based on assessment value K_i.

Strategy symbols	Strategies name	K_{ia}	K_{ib}	K_{ic}	Assessment value K_i	Ranking
S1	Developing a digitalized ecosystem for various supply chain partners	0.03258	2.00000	0.48776	1.156869	17
S2	Adequate management of investment for comprehensive digitalized business	0.06366	8.02340	0.95310	3.800048	3
S3	End to end Integration (horizontal/Vertical) of SC processes for better results of digitization and customization	0.05774	5.23922	0.86453	2.693348	15
S4	Developing an effective strategic alliance for collaborative scope	0.06345	6.99560	0.95003	3.419599	4
S5	Determined top management commitment for digitalization to gain the competitive edge	0.06679	12.09279	1.00000	5.317814	1
S6	Development of talent among the existing workforce for digitalization	0.06086	6.40858	0.91114	3.168494	8
S7	Adoption of govt policies and regulations related to digitization in SC	0.06011	5.71235	0.89993	2.900191	13
S8	Organizational flexibility and adaptability of new technology in SC	0.06328	6.53138	0.94738	3.245589	6
S9	Planning and coordination for implementing digital technologies in SC	0.06500	9.16953	0.97311	4.236477	2
S10	Awareness to build knowledge related to SC digitalization among existing employees	0.06110	6.32813	0.91477	3.141867	10
S11	Standardization of IT-enabled services for efficient integration of technologies	0.05586	6.08209	0.83639	2.982235	11
S12	Promoting an innovative culture among the workforce for better results of digitization	0.06001	5.72458	0.89849	2.903516	12
S13	Preparing the workforce through adequate training for managing digital activities in SC	0.06318	6.27968	0.94597	3.150949	9
S14	Adoption of new digital technologies for real-time product tracking	0.05568	5.68798	0.83364	2.833954	14
S15	Development of a proper network security system to prevent data privacy	0.06224	6.55165	0.93191	3.239604	7
S16	Adoption of digital transformation and automation for rich user experience	0.06363	6.85409	0.95264	3.369634	5
S17	Evaluating The value proposition for digital products and services	0.04482	4.28636	0.67108	2.172609	16

change to employees and inspire them to embrace new technologies, modify work processes, experiment with novel concepts, and work with internal teams [130]. "Inadequate strategic roadmap for digitalization (SB1)", "Lack of top management support and commitment (OB4)", and "Lack of governance mechanism adoption" (LB3) were ranked fourth, fifth, and sixth, with priority weights of 0. 0.0783, 0.0644 and 0.0614, respectively. The company's strategic roadmap for managing its digitization process may help manufacturers understand the need for digital evaluation and better support their digital transformation process [159]: Gökalp and Martinez [242]. Inadequate digital skill and capability is a major barrier for organizations that want to grow at a faster rate. As a result, management should develop digital skills among employees through proper training, which is only possible with positive commitment and support from management [243]. The lack of top management support is an important obstacle to successful DSC adoption [5,244]. Top management support is essential to present a clear vision about digital transformation initiatives [245]. Even though the SC's digitalization presents numerous opportunities, businesses around the world which are failing to capitalize on them due to a lack of top management support and commitment. Top management should involve and support employees in changing their mindsets for the organization to benefit from new advanced digital technologies [4]. As a result, top management should provide support and assistance throughout the planning and implementation of DSC. Top management involved in SC digitalization processes must pay close attention to the order of the DSCBs. These DSCB rankings are critical because they will assist various organizations in determining how to manage and mitigate the negative impact of DSCBs while successfully implementing DSC. The final ranking of the main barriers (Table 3) based on the global weights is as follows; SB (0.5044) > LB (0.2526) > OB (0.1281) > TB (0.0731) > FB (0.0419). This shows that the strategic barriers are the main influencers that will critically affect top management's decision-making and financial barriers are the least influential. The priority list of the remaining barriers is presented (Table 3).

The most important strategies for overcoming the effects of DSC implementation barriers were determined through a review of the literature and expert consultation. It is difficult to say which strategy is most important for DSC implementation. As a result, a comprehensive methodology was used to prioritize the strategies to aid decision-makers in selecting the best ones from the available options. CoCoSo is the methodology used to prioritize the strategies. The strategies were ranked based on the weights determined by the CoCoSo method, considering the weight of the DSC barriers determined by the SWARA method. The ranking obtained from calculated weights are as follows: S5 > S9 > S2 > S4 > S16 > S8 > S15 > S6 > S13 > S10 > S11 > S12 > S7 > S14 > S 3 > S17 > S1. The final ranking of DSC strategies based on the assessment value (K_i) is presented in Table 4. The ranking reveals that "Determined top management commitment for digitalization to gain the competitive edge" (S5) is the highest-ranked strategy because it is of prime importance in managing most of the barriers to DSC implementation. Digitization of SC in organizations requires significant resources such as skilled labour, a large initial investment, and time. These resources are provided by top management [246]. This strategy (i.e., Determined top management commitment to digitalization to gain a competitive edge, S5) would overcome the barriers such as SB1, SB2, SB3, SB4, SB5, OB4, OB5, TB1, TB2, TB5, FB3, FB4, FB5, LB1, LB2, and LB3. "Planning and coordination for implementing digital technologies in SC" (S9) is the second highest-ranked strategy to mitigate the DSC implementation barriers. Adoption of digital technologies in SC requires a huge initial investment, so investment management through adequate planning is the key to DSC implementation. This strategy (i.e. S9) would be useful in mitigating the barriers as OB1, OB3, TB3, TB4, FB2, FB4, LB1. "Adequate management of investment for comprehensive digitalized business" (S2) is the third highest-ranked strategy. Utilizing cutting-edge technologies that allow for real-time coordination and prompt activation of contingency strategies, integrated SC planning may reduce supply and time risks [26]. This strategy (i.e., S2) would mitigate the barriers such as OB2, FB1, LB4, LB5, LB6. "End to end Integration (horizontal/Vertical) of SC processes for better results of digitization and customization (S3)", "Evaluating the value proposition for digital products and services (S17)" and "developing a digitalized ecosystem for various SC partners" (S1) are among the low-ranking strategies. These strategies have minimal impact on the case organization. Developing a digitalized ecosystem for various SC partners has a negligible effect because their involvement in such activities is limited. Although low-ranking strategies are equally important to the organization, the ranking assists industrial practitioners in focusing on top-ranking solutions first and developing effective strategies for successful DSC implementation accordingly. Therefore, industrial practitioners must concentrate on the ranking order of solutions/strategies to lessen the effects of DSCBs. This would raise the chances of the successful implementation of the DSC.

6.1. Sensitivity analysis

A sensitivity analysis has also been carried out with the intention of evaluating the robustness of the proposed framework for analysing the strategies of DSC. In other words, the purpose of this analysis was to investigate how changing the criteria weights of the DSCBs would affect the overall ranking of the DSC strategies that are required to reduce the impact of the DSC barriers. Within the scope of this investigation, a total of twenty-five separate experiments were carried out, with the results of each one being documented in Table 5. In the first twenty-three experiments, the importance weight assigned to each barrier is increased by 0.6 for each DSCB, while the weights assigned to other barriers are kept at low and consistent levels. As a result, the weight of the first barrier, denoted by the symbol WSB1, is fixed at 0.6, and the weights of the remaining 24 barriers, denoted by symbols WSB2–WLB6, are substituted as equivalent or equal weights (i.e., 0.016667). Experiment 24th considers all the barriers as being of equivalent significance, so each one is given the same weight, which comes out to 0.04. In addition to this, the weight of barriers in the most recent experiment (WSB1–WLB3) is 0.045, while the weight of barriers assigned to the remaining barriers (WLB4–WLB6) is 0. The variation that occurs in the final rankings of the strategy to overcome barriers is depicted in Fig. 3 (i.e., that shows the result of sensitivity analysis), which shows how the weights of the barriers can have an effect.

The assessment value (K_i) is the criterion used by the CoCoSo method to determine the priority. The higher the value of K_i, the higher the priority sequence of the DSC strategy among all the other strategies that were taken into consideration. Based on the findings, strategy S5 (Determined top management commitment for digitalization to gain the competitive edge) has achieved the highest assessment value K_i out of the twenty-two experiments that were carried out (i.e., 1–7, 9–12, 15–25). Also, strategy S5 has achieved the highest value of K_i (K_i = 9) in experiment number twelve. Meanwhile, strategy S9 (Planning and coordination for implementing digital technologies in SC) has achieved the highest assessment value K_i in two experiments (i.e.,13, 14) and strategy S2 (Adequate management of investment for comprehensive digitalized business) has achieved the highest assessment value in one experiment (i.e.,8). As per the results, strategy S5 had the highest K_i values in more than 80% of experiments among all the strategies. Strategy S1 (Developing a digitalized ecosystem for various supply chain partners) has obtained the lowest assessment value K_i out of the seventeen experiments that were carried out (i.e., 1–5, 7–12, 14–16, 19, 20, 22). From the results strategy, S1 obtained the lowest score in more than 60% of the experiments. Therefore S1 (Developing a digitalized ecosystem for various supply chain partners) is considered as the least important strategy among all the strategies. As the weights assigned to different DSCBs change, the priorities of the remaining strategies change significantly. Therefore, it can be concluded that the proposed research model is robust and that the ranking of solutions is relatively sensitive to barriers weights.

7. Implications of the research

7.1. Theoretical implications

This research paper contributed by providing a detailed understanding and knowledge of several barriers/obstacles to the DSC as well as various strategies (i.e., solutions) to overcome these barriers. The proposed framework of the study has enough potential for assisting business managers to identify critical barriers and mitigating strategies for the successful implementation of digitalization. It will assist the decision-makers in the automobile industry to mitigate prevailing obstacles/challenges regarding digital transformation and direct them to select the most suitable strategies within confined resources. The current research presents a decision-supported and empirically tested framework for practitioners that links DSC barriers and mitigation measures or strategies that are useful to mitigate the impact of these DSC barriers. The research considers the Indian automobile industry although the implications of the study are also applicable to other countries' automobile sectors with similar organizational structures. The current study offers industrial firms a framework to use as they attempt to remove these obstacles/barriers. In the context of automobile sectors, this study highlights 25 obstacles to DSC implementation. Organizations can seek to overcome these obstacles to become innovative by adopting digitization.

7.2. Managerial implications of this research

The proposed framework helpful to practitioners in adopting DSC by having a detailed understanding about the barriers and mitigation strategies to manage the DSCBs effectively. This research would benefit managers to adopt DSC more easily. It is difficult to implement DSC in an organization when knowledge of DSC barriers and DSC strategies is lacking, and when the significance of these factors is not evaluated. As a result, it is of the utmost importance for managers to have a comprehensive understanding of the various obstacles that could prevent the implementation or adoption of DSC activities within the organization. This research also makes it easier for practitioners to manage many difficulties, obstacles, and challenges that are associated with DSC by providing them with an efficient solution approach (i.e., strategy) for the successful adoption of DSC. Also, this would help managers in the process of formulating the key strategies for handling barriers during the early phase of DSC implementation. In addition, it is not possible to put into action all the strategies at the same time. As a result, the priority sequence list would assist industry managers in concentrating their efforts on strategies that offers the highest probability of the DSC implementation being successful. In essence, the findings of this research offer practitioners some key points that should be adhered to in the process of developing their DSC operational activities in the short-term and long-term to ensure successful DSC implementation. They could use this information to better design their strategy to successfully implement DSC.

This research can also assist managers to adopt team commitment, collaborative practices, and efficient fund management for transforming their business from conventional to digitalize. The framework is

Table 5
Sensitivity analysis with respect to marginal changes in criteria weight.

Experiments	Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7	Ex8	Ex9	Ex10	Ex11	Ex12	Ex13
Definitions	WSB1=0.6 WSB2– WLB6 = 0.016667	WSB2 = 0.6 WSB1, WSB3– WLB6 0.016667	WSB3 = 0.6 WSB1– WSB2 = 0.016667 WSB4– WLB6 = 0.016667	WSB4 = 0.6 WSB1– WSB3 = 0.016667 WSB5– WLB6 = 0.016667	WSB5 = 0.6 WSB1– WSB4 = 0.016667 WOB1– WLB6 = 0.016667	WOB1 = 0.6 WSB1– WSB5 = 0.016667, WOB2– WLB6 = 0.016667	WOB2 = 0.6 WSB1– WOB1 = 0.016667 WOB3– WLB6 = 0.016667	WOB3 = 0.6 WSB1– WOB2 = 0.016667, WOB4– WLB6 = 0.016667	WOB4 = 0.6 WSB1– WOB3 = 0.016667, WOB5– WLB6 = 0.016667	WOB5 = 0.6 WSB1– WOB4 = 0.016667, WTB1– WLB6 = 0.016667	WTB1 = 0.6 WSB1– WOB5 = 0.016667, WTB2– WLB6 = 0.016667	WTB2 = 0.6 WSB1– WTB1 = 0.016667, WTB3– WLB6 = 0.016667	WTB3 = 0.6 WSB1– WTB2 = 0.016667 WTB4– WLB6 = 0.016667
S1	1.2	1.2	1.2	1.2	1.1	2.5	1.1	1.2	1.2	1.2	1.2	1.2	2.0
S2	5.1	4.8	4.5	4.5	3.7	2.9	3.5	4.2	3.3	4.3	2.7	6.5	2.9
S3	2.9	3.1	3.2	4.0	1.9	1.9	2.2	3.3	3.1	4.5	2.1	4.4	2.9
S4	3.6	4.6	4.0	4.2	2.6	2.3	2.1	4.5	2.9	3.9	2.4	5.0	3.5
S5	6.2	6.2	6.2	6.2	4.6	3.8	3.8	4.7	6.2	6.2	3.8	9.0	3.8
S6	3.1	4.2	4.0	4.2	2.3	2.0	2.3	3.1	3.4	4.4	3.2	5.8	3.1
S7	3.3	4.0	2.9	5.0	2.4	1.9	2.2	3.2	3.3	4.0	1.8	4.2	3.2
S8	2.7	4.7	4.0	3.2	2.6	2.3	2.1	3.7	3.2	3.3	2.0	4.1	3.1
S9	5.1	5.4	5.3	5.4	4.0	3.7	2.4	5.7	4.7	4.2	2.5	6.7	4.6
S10	3.2	3.8	4.2	3.8	2.1	2.4	2.6	2.3	2.9	5.0	3.0	4.5	3.6
S11	2.9	3.9	3.4	4.0	2.4	2.4	1.8	2.3	4.2	2.6	1.7	4.3	2.9
S12	2.7	4.0	3.5	3.4	2.2	2.0	2.0	2.9	2.7	3.1	1.8	4.2	3.2
S13	2.9	3.9	4.2	3.9	2.3	2.2	2.1	3.5	3.3	3.7	2.3	4.0	3.5
S14	3.0	3.6	4.1	3.7	2.0	1.7	2.4	2.6	2.4	2.8	2.2	4.1	2.6
S15	2.5	3.6	4.6	3.9	2.4	3.0	2.2	3.1	3.0	3.4	2.2	4.1	3.6
S16	3.2	4.8	3.8	4.1	2.6	2.3	2.5	3.4	3.3	3.6	2.3	4.6	2.8
S17	2.1	2.8	3.0	2.7	1.8	2.0	1.9	1.9	1.8	2.2	1.7	3.4	1.5

Experiments	Ex14	Ex15	Ex16	Ex17	Ex18	Ex19	Ex20	Ex21	Ex22	Ex23	Ex24	Ex25
Definitions	WTB4 = 0.6 WSB1– WTB3 = 0.016667 WTB5– WLB6 = 0.016667	WTB5 = 0.6 WSB1– WTB4 = 0.016667 WFB1– WLB6 = 0.016667	WFB1 = 0.6 WSB1– WTB5 = 0.016667 WFB2– WLB6 = 0.016667	WFB2 = 0.6 WSB1– WFB1 = 0.016667 WFB3– WLB6 = 0.016667	WFB3 = 0.6 WSB1– WFB2 = 0.016667 WFB4– WLB6 = 0.016667	WFB4 = 0.6 WSB1– WFB3 = 0.016667 WLB1– WLB6 = 0.016667	WLB1 = 0.6 WSB1– WFB4 = 0.016667 WLB2– WLB6 = 0.016667	WLB2 = 0.6 WSB1– WLB1 = 0.016667 WLB3– WLB6 = 0.016667	WLB3 = 0.6 WSB1– WLB2 = 0.016667 WLB4– WLB6 = 0.016667	WLB4 = 0.6 WSB1– WLB3 = 0.016667 WLB4– WLB6 = 0.016667	WSB1– WLB6 = 0.04	WSB1– WLB3 = 0.045 WLB4– WLB6 = 0
S1	1.2	1.2	1.2	2.7	1.7	1.2	1.2	1.8	1.1	1.4	1.2	1.1
S2	3.2	3.6	5.5	3.3	2.4	3.3	2.8	3.2	2.6	3.6	2.7	2.9
S3	3.0	2.8	4.9	3.3	2.6	2.8	3.1	2.9	2.1	1.8	2.1	2.5
S4	3.0	3.4	4.5	3.9	3.3	5.2	3.9	3.4	3.7	2.6	2.6	2.9
S5	3.8	6.2	6.1	5.2	5.4	6.0	5.8	5.4	4.3	3.9	3.4	4.0
S6	3.1	3.9	4.3	3.5	2.8	3.3	3.1	2.8	2.1	2.8	2.4	2.7
S7	2.9	3.4	4.8	3.6	3.0	3.9	3.5	3.1	2.5	2.4	2.3	2.6
S8	3.1	3.6	4.4	4.0	3.4	3.7	2.5	3.1	2.4	2.5	2.3	2.6
S9	4.6	4.3	4.5	4.9	3.2	5.7	5.7	4.4	2.6	2.4	2.8	3.4
S10	2.4	3.6	4.1	3.6	2.8	3.6	3.0	3.0	2.2	2.4	2.3	2.7
S11	2.7	3.7	4.2	3.1	2.6	3.3	4.1	2.9	2.4	2.5	2.2	2.5
S12	2.6	3.2	4.3	4.1	2.4	3.0	3.1	2.8	1.8	2.2	2.1	2.5
S13	4.3	3.6	3.5	4.3	2.6	3.2	3.8	2.8	2.4	2.5	2.4	2.7
S14	2.8	3.0	3.3	2.6	2.7	3.2	3.7	1.9	1.8	2.3	2.0	2.3
S15	3.4	4.7	4.0	3.1	2.2	3.5	3.1	3.1	2.4	3.2	2.4	2.7
S16	3.6	3.7	4.3	3.6	3.0	3.5	3.4	3.4	2.7	2.5	2.4	2.8
S17	1.5	2.6	2.7	1.5	1.5	2.2	2.8	1.5	1.6	1.6	1.5	1.9

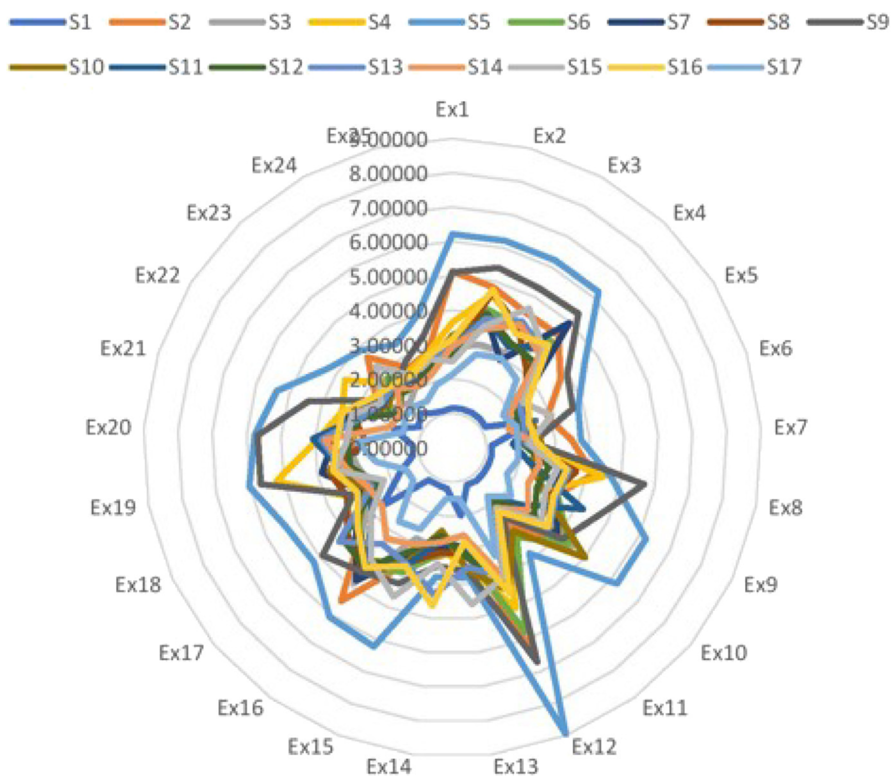

Fig. 3. Result of sensitivity analysis.

successfully tested by sensitivity analysis and approved by industrial experts, so it will guide the practitioner to select the optimal strategies within the available resources. Using the suggested framework, practitioners might develop regulations for organizations. If practitioners deeply understood these criteria, they may successfully overcome DSC barriers. In a practical situation, it could be difficult for the managers to concentrate and allocate enough resources to all types of barriers. Management should thus concentrate on looking at the top-ranked barriers and ensure efficient strategic actions which might be implemented to overcome them before they become crucial. The suggested framework also included seventeen strategies for reducing the effects of DSC barriers which might be useful for manager and decision makers at the initial planning stage, practitioners must embrace these strategies in the order of priority, which then enables them to create both short and long-term business arrangements for the implementation of the DSC. The chances of failure during the implementation of the DSC would be reduced by choosing the best ways to overcome the effects of the various barriers.

8. Concluding remarks

The management of DSCBs is critical because they have a negative impact on the operational efficiency of the organizations. The adverse impact of these barriers could be managed or mitigated by implementing the robust strategies for DSC. However, without knowing the relative importance of DSCB mitigation strategies, industrial practitioners will find it difficult to implement them. As a result, the ranking of strategies would assist industrial practitioners in implementing these strategies in a systematic manner to effectively manage digitalization practices in SC. The automobile organizations have several obstacles such as SC traceability, transportation, and assembly. The DSC can significantly overcome these challenges by its advanced technologies such as IOT, BDA, robotics, AGVs, etc. The present study proposes a framework based on the hybrid modified SWARA-CoCoSo methodology to prioritize DSC strategies so that barriers to its adoption can be effectively mitigated. The input data for this research were obtained from industrial professionals in the Indian Automobile industry. The extensive literature review and expert opinions led to the finalization of 25 key barriers and 17 strategies for successful DSC implementation. The twenty-five identified DSCBs were categorized into five subsections namely strategic barriers, organizational barriers, leadership barriers, financial barriers, and technological barriers. A hybrid framework of SWARA and CoCoSo was used to evaluate all twenty-five DSCBs and seventeen strategies. SWARA was used to calculate the relative importance weights of DSCBs. The rankings of the strategies were then determined using CoCoSo. To demonstrate the proposed framework's applicability, an empirical case study analysis of an Indian automobile part manufacturing organization was conducted. The analysis was carried out with the help of four experts with relevant industrial and research experience for dealing with digitalization-related practices within the organization. Table 3 shows analysis done by the SWARA method to prioritize the identified DSCBs which reveals that "lack of urgency for supply chain digitalization", "lack of proper innovation strategies", and "Inadequate leadership to lead digital transformation" are the three most significant barriers to DSC implementation. Table 3 also shows the priority list of additional barriers to DSC implementation. While "determined top management commitment for digitalization to gain the competitive edge", "planning and coordination for implementing digital technologies in SC", and "Adequate management of investment for comprehensive digitalized business" emerge as the three most critical strategies for reducing the impact of DSCBs, according to the results of the CoCoSo method (see Table 4). Table 4 also shows the priority list of additional strategies useful for mitigating the impact of DSCBs. The findings of current research also indicated that growth of DSC has significant impact on automobile sector.

The outcome of the current research presents a decision-supported and empirically tested framework for practitioners and researchers that links DSCBs and mitigation measures or strategies that are useful to mitigate the impact of these DSCBs, which would aid researchers as

Table 6
Rating for main barriers.

Main barriers		Sub barriers									
Main barriers (j)	Relative significance 1–100	Strategic barriers (j)	Relative significance 1–100	Leadership barriers (j)	Relative significance 1–100	Organizational barriers (j)	Relative significance 1–100	Technological barriers (j)	Relative significance 1–100	Financial barriers (j)	Relative significance 1–100
SB		SB1		LB1		OB1		TB1		FB1	
LB		SB2		LB2		OB2		TB2		FB2	
OB		SB3		–		OB3		TB3		FB3	
TB		SB4		LB5		OB4		TB4		FB4	
FB		SB5		LB6		OB5		TB5			

well as practitioners in formulating a plan for the successful implementation of DSC in Indian Automobile organizations. The practitioners can focus on strategies of DSC based on their prioritized sequence for effective implementation of digitalization practices in SC. A sensitivity analysis was also performed to demonstrate that the rankings are robust and sensitive to the weights of the experts' opinions. The results of sensitivity analysis have been presented in Table 5 and Fig. 2. The current study provides a critical roadmap for practitioners and researchers to understand both the barriers and strategies associated with DSC implementation in a single study.

This paper has some drawbacks, which opens the door to future research opportunities. The data used for SWARA-CoCoSo calculations (i.e., weight computation during pairwise comparison matrixes for DSC barriers) is based on the opinions of experts' panel, which can vary depending on their experience, interest, and knowledge. This study is performed on Indian automobile organization and further research can be conducted on other field such as manufacturing, management, food sector, and agriculture sector. Also, the findings and implementation of the suggested framework can be generalized to industries in other sectors that want to adopt digitization practices in SC. In future, researchers can compare and evaluate the results of this paper using various advanced MCDM techniques, such as LBWA, OPA, FUCOM, MARCOS, RAFSI, VIKOR, MAIRCA etc. SWARA-CoCoSo can be integrated with fuzzy sets, intuitionistic fuzzy sets, Pythagorean fuzzy sets, and neutrosophic sets in the future to overcome issues related to subjectivity, vagueness, and uncertainty while capturing data from experts.

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Declaration of competing interest

In connection to the current research there is no conflict of interest.

Data availability

Data will be made available on request.

Appendix A

Data collection steps to assess the relative importance of main criteria and sub-criteria barriers of DSC (Tables 6, 7).

Steps for Filling the table of DSC Barriers:

Step A. Arrange the criteria (j) in descending order of expected importance.

Step B. Rate the criteria on relative significance value 1–100. The most important criteria will be assigned a significance value of 100.

Step C. Beginning with the second criterion, indicate the relative importance of criterion j in relation to the earlier ($j-1$) criterion.

Steps for data collection to rate the strategies of DSC Barriers:

Step A. Please rate the impact of a specific solution on barriers on a scale of 1 to 10 in the Table 10. The most important criteria will be assigned a significance value of 10.

Appendix B

The steps required to obtain the weights of major criteria barriers and sub-criteria barriers of DSC using the modified SWARA methodology are shown in Table 11. The response was aggregated using geometric mean after input data was collected from three expert groups (E1, E2, E3, and E4).

Table 7
Rate the effectiveness of strategies for overcoming DSC barriers.

		DSC barriers								
		SB1	SB2	SB3	–	–	–	LB4	LB5	LB6
Strategies for DSC	S1									
	S2									
	S3									
	–									
	–									
	–									
	S15									
	S16									
	S17									

Table 8
SWARA calculation for main and sub-criteria based on responses from expert groups.

Main criteria	S_j	$K_j = S_j + 1$	q_j	w_j
SB	0	1	1	0.5044
LB	0.9971	1.9971	0.5007	0.2526
OB	0.9720	1.9720	0.2539	0.1281
TB	0.7526	1.7526	0.1449	0.0731
FB	0.7429	1.7429	0.0831	0.0419
Sub criteria	S_j	$K_j = S_j + 1$	q_j	w_j
SB3	0	1	1	0.4580
SB2	0.8500	1.8500	0.5405	0.2475
SB1	0.5941	1.5941	0.3391	0.1553
SB5	0.7695	1.7695	0.1916	0.0878
SB4	0.7061	1.7061	0.1123	0.0514
Sub criteria	S_j	$K_j = S_j + 1$	q_j	w_j
OB4	0	1	1	0.5026
OB2	0.9823	1.9823	0.5045	0.2535
OB5	0.9211	1.9211	0.2626	0.1320
OB3	0.8472	1.8472	0.1422	0.0714
OB1	0.7666	1.7666	0.0805	0.0404
Sub criteria	S_j	$K_j = S_j + 1$	q_j	w_j
TB2	0	1	1	0.4843
TB4	0.8615	1.8615	0.5372	0.2602
TB5	0.8304	1.8304	0.2935	0.1421
TB3	0.9624	1.9624	0.1495	0.0724
TB1	0.7709	1.7709	0.0844	0.0409
Sub criteria	S_j	$K_j = S_j + 1$	q_j	w_j
FB3	0	1	1	0.5131
FB1	0.9204	1.9204	0.5207	0.2672
FB2	0.8945	1.8945	0.2749	0.1410
FB4	0.7935	1.7935	0.1533	0.0786
Sub criteria	S_j	$K_j = S_j + 1$	q_j	w_j
LB2	0	1	1	0.4741
LB3	0.9490	1.9490	0.5131	0.2432
LB4	0.8252	1.8252	0.2811	0.1333
LB5	0.7850	1.7850	0.1575	0.0747
LB1	0.6338	1.6338	0.0964	0.0457
LB6	0.5724	1.5724	0.0613	0.0291

Appendix C

The steps required to rank the strategies mitigating the barriers of DSC using the CoCoSo methodology are shown in Tables 10 to 14. The geometric mean of the values was used to aggregate the input data from the four expert groups (E1, E2, E3 and E4).

Table 9
Calculation of global weights of sub-criteria.

Main criteria	Relative weight	Sub criteria	Relative weight	Global weight
SB	0.504378	SB1	0.1553	0.078330
		SB2	0.2475	0.124833
		SB3	0.4580	0.230987
		SB4	0.0514	0.025944
		SB5	0.0878	0.044264
LB	0.25255	LB1	0.0457	0.011540
		LB2	0.4741	0.119729
		LB3	0.2432	0.061431
		LB4	0.1333	0.033656
		LB5	0.0747	0.018855
		LB6	0.0291	0.007339
OB	0.128069	OB1	0.0404	0.005179
		OB2	0.2535	0.032466
		OB3	0.0714	0.009150
		OB4	0.5026	0.064368
		OB5	0.1320	0.016902
TB	0.073075	TB1	0.0409	0.002989
		TB2	0.4843	0.035393
		TB3	0.0724	0.005293
		TB4	0.2602	0.019013
		TB5	0.1421	0.010387
FB	0.041928	FB1	0.2672	0.011203
		FB2	0.1410	0.005913
		FB3	0.5131	0.021515
		FB4	0.0786	0.003297

Table 10
The initial decision matrix.

	SB1	SB2	SB3	–	–	–	LB4	LB5	LB6
S1	4.9492	3.1302	4.4721	–	–	–	5.6924	7.9686	4.9492
S2	8.2391	7.2004	6.7007	–	–	–	8.2391	8.4853	8.2391
S3	5.9579	4.9492	5.7327	–	–	–	4.7287	6.2357	5.4772
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–
S15	5.1800	5.4772	7.2004	–	–	–	7.7069	5.9579	5.9579
S16	5.9579	7.4833	6.1601	–	–	–	5.9579	6.1920	6.1920
S17	5.7327	5.4772	6.1920	–	–	–	5.4772	5.4772	3.9360

Table 11
Calculation of normalized decision matrix.

	SB1	SB2	SB3	–	–	–	LB4	LB5	LB6
S1	0.0000	0.0000	0.0000	–	–	–	0.2745	0.8282	0.2227
S2	0.8681	0.7601	0.6374	–	–	–	1.0000	1.0000	0.9459
S3	0.2662	0.3397	0.3605	–	–	–	0.0000	0.2522	0.3388
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–
S15	0.0609	0.4383	0.7803	–	–	–	0.8484	0.1598	0.4444
S16	0.2662	0.8129	0.4828	–	–	–	0.3502	0.2376	0.4959
S17	0.2067	0.4383	0.4919	–	–	–	0.2132	0.0000	0.0000

Table 12
Obtaining the sum of the weighted comparability sequence (S_i) for each alternative.

	SB1	SB2	SB3	–	–	–	LB4	LB5	LB6	SI
S1	0.0000	0.0000	0.0000	–	–	–	0.0092	0.0156	0.0016	0.0955
S2	0.0680	0.0949	0.1472	–	–	–	0.0337	0.0189	0.0069	0.5826
S3	0.0208	0.0424	0.0833	–	–	–	0.0000	0.0048	0.0025	0.3323
–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–
S15	0.0048	0.0547	0.1802	–	–	–	0.0286	0.0030	0.0033	0.4452
S16	0.0208	0.1015	0.1115	–	–	–	0.0118	0.0045	0.0036	0.4701
S17	0.0162	0.0547	0.1136	–	–	–	0.0072	0.0000	0.0000	0.2790

Table 13
Obtaining The total power weight of the comparability sequences (P_i) for each alternative.

	SB1	SB2	SB3	–	–	–	LB4	LB5	LB6	Pi
S1	0.0000	0.0000	0.0000	–	–	–	0.9924	0.9960	0.9951	12.5142
S2	0.9890	0.9663	0.9012	–	–	–	1.0000	1.0000	0.9998	24.0571
S3	0.9015	0.8739	0.7901	–	–	–	0.0000	0.9708	0.9964	22.0177
–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–
S15	0.8032	0.9022	0.9443	–	–	–	0.9990	0.9613	0.9973	23.6466
S16	0.9015	0.9745	0.8452	–	–	–	0.9938	0.9696	0.9977	24.1575
S17	0.8838	0.9022	0.8488	–	–	–	0.9909	0.0000	0.0000	17.0697

Table 14
Obtaining the relative weights (ie., K_{ia}, K_{ib} and K_{ic}) and determining the assessment value (K_i) of the alternatives.

Strategies	K_{ia}	K_{ib}	K_{ic}	Assessment value K_i
S1	0.0326	2.0000	0.4878	1.1569
S2	0.0637	8.0234	0.9531	3.8000
S3	0.0577	5.2392	0.8645	2.6933
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–
S15	0.0622	6.5516	0.9319	3.2396
S16	0.0636	6.8541	0.9526	3.3696
S17	0.0448	4.2864	0.6711	2.1726

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