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Sustainable Performance through Digital Supply Chains in Industry 4.0 Era: Amidst the Pandemic Experience

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Abstract: Amidst the COVID-19 pandemic disruption, industry 4.0 technologies (I4TEs) and digital supply chains (DSCs) are reinforcing businesses to gain economic stability and agility to enrich their sustainable performance (S.P.). Survey methods have been deployed based on the constructs obtained from the literature. Data collection through a survey resulted in 202 valid responses. Confirmatory factor analysis (CFA) confirms the constructs and the mediating effect of the DSCs through partial least squares structural equation modeling (PLS-SEM). The study is among the few studies that examine the I4TE impact on DSCs and S.P. The results show that industry 4.0 technologies enhance the sustainable performance of firms. Results also show a complete mediation of DSCs on the interrelationship between I4TEs and S.P. Those DSCs with I4TE inclusion can transform an organization's strategic decision-making. For the authors, this study is the first of its kind. Although some of the literature explored different aspects of the concept of industry 4.0 and digitalizing supply chains, studies have yet to specifically evaluate the potential impacts of digital supply chains on sustainable performance. The novelty of DSCs is their support of firms in improving their preparedness, agility, and transparency to strengthen their sustainable performance. These DSCs will provide agile, collaboration, responsiveness, end-to-end visibility, and resilient supply chains to diminish supply risk and enrich preparedness and responsiveness to recuperate quickly from uncertainty amidst the pandemic. The study will help managers re-designing their strategic planning, resulting in new cost reduction and resilience models for supply chains. The study calls for firms to employ multiple DSCs once they have set clear strategic priorities. The overall findings of the work fill the literature gaps of studies in the digitalization of supply chains.

Keywords: industry 4.0 technologies (I4TEs); digital supply chain (DSC); supply chain 4.0; resilience; sustainable performance (S.P.); pandemic

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1. Introduction

The world has been witnessing a challenge in managing and controlling the disruption caused due to the pandemic. The current disruptive scenario has raised serious concerns about the operational capabilities of organizations to survive and respond appropriately during this challenging time. Small firms cannot respond in this difficult time. However, global supply chains (GSCs) are also extensively challenged to design and manage their survivability and resiliency to sustain their operations during the crisis [1]. The core strategy of GSCs is now reliant on industry 4.0 technologies (I4TEs) that empower organizations with benefits such as real-time information, advanced analytics, manufacturing, and automation [2]. By including I4TEs, firms create open and intelligent platforms for improvising products, processes, and services [3,4]. Therefore, GSCs can transform their current systems into digital supply chains (DSCs) to enhance products and services and fulfill the end-users dynamic needs. DSCs have enhanced the performance of firms over the last few years [5,6]. The term "Supply Chain 4.0" has been used in the literature to conceptualize capturing the critical essence of industry 4.0 within the supply chains [6]. In the presence of industry 4.0 technologies, developing DSCs is the strategic perspective of supply chain 4.0 [7]. DSCs have also been responsible for reducing transaction costs for business operations, as well as supporting them to become more resilient, visible, and transparent [6–8]. Meanwhile, GSCs are transforming their supplier network configurations with support from I4TEs during the pandemic [9,10]. During the process, DSCs have also proven their excellence in enhancing the performance of firms, yet more is needed for survival and sustaining in the current disruptive business environment. DSCs need improvement with intelligent and interlinked supply chain networks that bring all partners onto a single platform. Thus, there is a need for multiple chains, collectively called a digital supply chain, where all S.C. parties assemble to formulate a digital ecosystem that digitally communicates through a real-time information exchange that aims to enhance the firm's performance [11–13]. Due to the convergence with industry 4.0, DSCs are highly integrated and accessible and ensure flawless information flow that enhances the organization's operational effectiveness [14]. Nevertheless, the linear S.C. process flow remains unchanged, and the data flow in the S.C. nodes is real-time [15]. This interconnection between processes and developed sub-processes has transformed traditional supply chains into sustainable and effective predictive networks with lower transaction costs and an enhanced ability to trade with distinct partners [16]. The pandemic has created an opportunity for DSCs to support firms in developing their preparedness, agility, and transparency to enhance their sustainable performance. These DSCs aim to provide agile, collaborative, responsive, and end-to-end visibility; the emerging and resilient S.C.s reduce overall risk while enhancing preparedness and responsiveness to recover from the disruption [17]. Further, DSCs revolutionized the S.C. processes to conquer the functional limitations of linear supply chains [18,19]. DSCs allow more excellent connectivity in those areas that previously did not exist. The online site of three-dimensional printers making replacements to reduce downtime, drone video monitoring of remote worksites, and other IoT technologies transform the existing processes to enhance the organization's sustainable performance [20]. Meanwhile, the pandemic experience has opened up a new dimension for the sustainability of manufacturing organizations [21]. Companies must be resilient to survive during and post-pandemic and thus need appropriate and cost-efficient decision-making using real-time and I4TEs applications [22]. Achieving sustainable performance through cost reduction, minimization of latency, and risk mitigation is challenging; thus, adopting dynamic business practices through advanced, interconnected, and intelligent networks of DSCs, along with I4TEs, can be a productive solution to develop robust and resilient supply chains [23]. Past studies in DSC and SCM have stressed single dimensions, transparency [24], ripple effect [25], blockchain technology in SCM [26], and traceability [27], to measure the effect on the performance of the firms. However, how DSC can affect the organization's performance is untouched. Although past research has proven that I4TEs may enhance a business's S.P., it still needs to be explored in the DSC context. Thus, based on the previous literature, in the context of developing economies, the study aims to address the following research objectives:

RO1: To determine the various dimensions of DSCs that can determine the survival and sustainability of business firms during and after the pandemic.

RO2: To evaluate the operational efficiency and survival commitment of DSC of business firms.

RO3: To understand and evaluate the influence of digital technologies selection and sustainable performance of business firms.

In addition, the current study endeavors to discuss and answer research questions that are aimed at uncovering the influence of DSC on the sustainable performance (S.P.) of the firm, including:

RQ1: What are the dimensions of DSCs that would help firms to survive amidst the pandemic?
RQ2: Are the digital supply chains capable of enhancing operational efficiency and achieving sustainable goals with a mediating effect of DSC?
RQ3: How do DSCs influence I4TEs and the S.P. of the business firms?

The underpinning theories for the study are from information processing theory (IPT), which argues that an economic system enhances a firm's efforts to channel digital resources for sustainable business performance and the enhancement of quality and capability [28,29]. The information exchange rate improved decision-making capabilities with the emergence of digital information processing infrastructure under DSC. The enhanced information processing capability enriches the sustainable performance of the firms. Based on IPT, a sample of 202 industry professionals from multiple firms was collected to understand the influence of DSCs on the S.P. of firms by developing extended construct-based models on DSCs, I4TEs and S.P. Considering the relevance of supply networks and digitization in S.C.s, this study has adapted the IPT model to explore the effect of DSCs on sustainable performance. This study has three main contributions. Firstly, the study establishes a link among I4TEs, DSCs, and the S.P. of a business using IPT theory to understand the importance of real-time information communication's significance for developing integrated intelligent systems and appropriate decision-making. Secondisdly, the intermediating role of DSCs on I4TEs and S.P. is proposed. The DSCs are evaluated to measure their impact on the S.P. of the firm and also how it can amplify the performance based on I4TEs. Last, but not least, the research deliberates on the role of DSCs in handling disruption in the post-pandemic era. The disposition of the research is as follows. Section 2 discussed the academic works on I4TEs, DSCs, and S.P. and other elements from past literature. Section 3 explained the methods and material. Section 4 discussed the analysis of the study. Section 5 provides research implications of the study. Finally, Section 6 summarizes the research, with restrictions and future directions for research.

2. Literature Review

The literature review exercise explained a comprehensive approach to exploring the relevant literature on I4TEs, DSCs, DSCs, and S.P. The database "Scopus" and "Web of Science" were searched for the literature on DSCs, dimensions of DSCs, organizational performance, and I4TEs. The relevant papers extracted through the steps are shown in Figure 1. The search was based on "Digital supply networks," OR "Industry 4.0" OR "Sustainable organizational performance," OR "Dimensions of Supplier networks" OR "Digital supply chains." A combination of keywords was used to obtain the relevant results. The research is confined to the timeline "2010–2022". Figure 1 shows the steps to extract relevant papers for the current study.

The articles follow the guidelines under the PRISMA framework for the comprehensive literature review. The framework follows a four-step process, including: (a) identification, (b) screening, (c) eligibility and exclusion, and (d) inclusion.

Under the first step, identification, the authors underwent data collection from two databases, including Scopus (n = 255) and Web of Science (n =106). In the second step, 197 records were obtained after removing the duplicated entries. After removing the duplicates, it came down to 54; this was narrowed down only to journal articles, which resulted in 48 journal articles. The third step was the exclusion of unrelated articles, which retained 42 articles, and, finally, abstract checking resulted in 28 papers. The fourth step is the involvement in the final inclusion from the selected papers, and factors were identified.

The exclusion and inclusion process used omission, review, and shortlisting articles to reduce 435 articles (initially) to the final value of 33 articles. The PRISMA flow diagram exhibits the systematic literature review (SLR) process performed in the study.

The SLR followed an expert survey, where each expert thoroughly read the description of these critical factors in the questionnaire and evaluated them according to their significance in enhancing organizational effectiveness. The detailed elaboration of the industry

4.0 technologies that can enhance the sustainable performance of digital supply chains is discussed in Sections 2.1 and 2.2. Their definition and scope is mentioned in Appendix A.

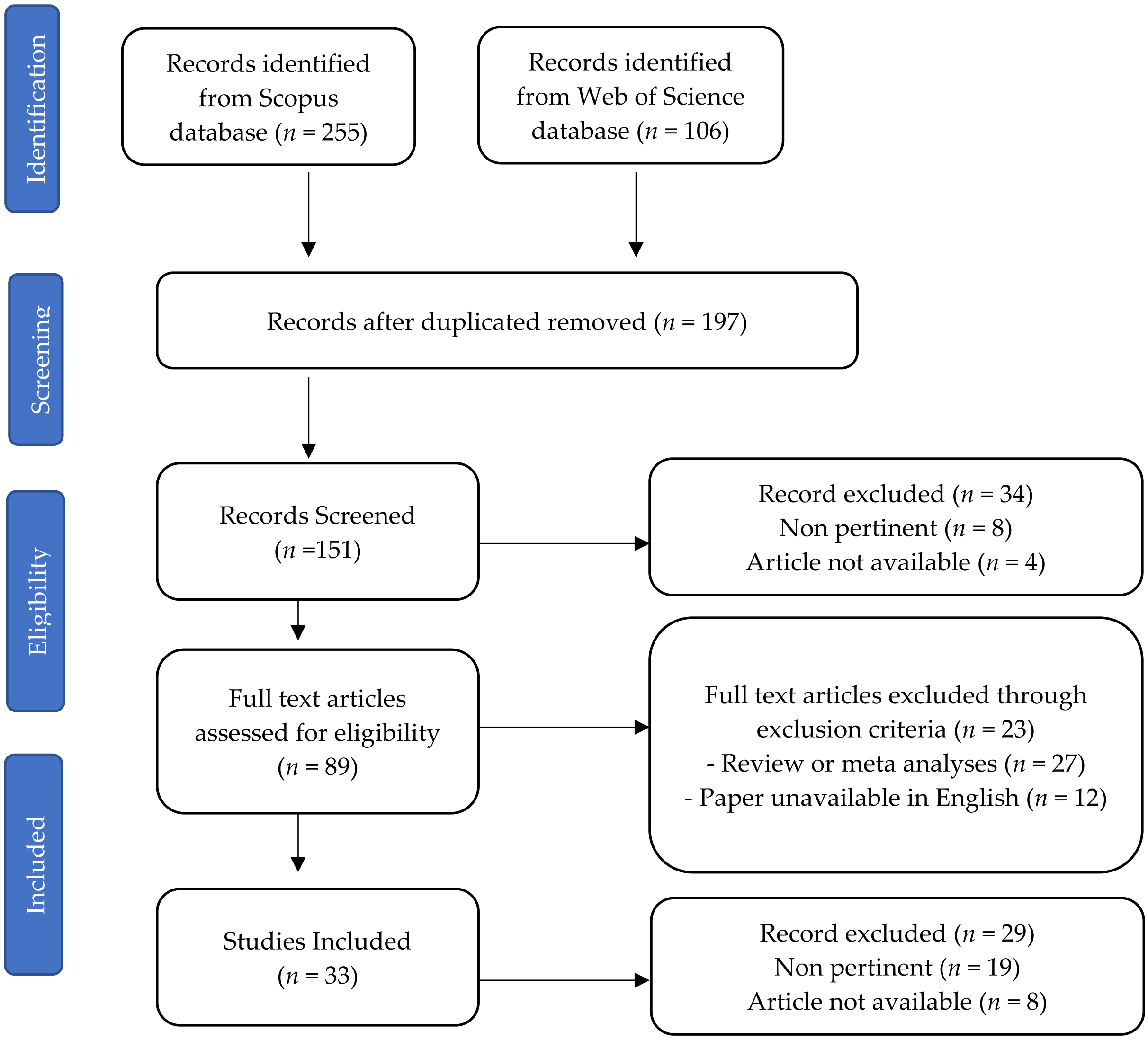

Figure 1. PRISMA flow diagram.

2.1. Industry 4.0 Technologies (I4TEs)

Due to changing market dynamics and consumer needs, organizations are revisiting and adapting their existing processes. Managers are constantly looking toward adopting advanced technologies to improve their S.C.s and achieve their sustainability goals [30–34]. The sustainability perspective of systems needs to be understood, and thus, organizations are exploring new technologies that might help them succeed [35]. Various digital technologies under IE 4.0 are adapted by organizations to improve their processes. These technologies have emerged as highly productive technologies to attain sustainable business performance. The key objective of I4TEs is to develop a highly integrated, real-time responsive, and efficient manufacturing system [36]. These technologies enabled backward and forwarded integration in the value chain. Multiple technologies result in robust data extraction, storage, and dissemination, with or without human intervention [18,37]. I4TEs enable the high quality of data to bring economies of operation and faster and flawless services among S.C. partners. The other commercial advantage of I4TE is enhancing information quality for routine business communication in S.C. and training purposes. I4TE-lead digital technologies can improve operations in a disruptive environment amidst a pandemic.

2.2. Digital Supply Chains

The impact of digitalization has been assessed and found to be significant for decision-making through a distributed network of integrated digital and physical loops [19,20]. Straub [38] evaluated the significance of digital supply chains for information generation and sharing among suppliers. The study showed that the supply network could be improvised with digital technologies, primarily through I4TEs. Over time, the need for supply networks to obtain upgraded will be due to the convergence with digital technologies. Supply chain networks have become real-time, agile, resilient, and lean [39,40]. The primary property of such networks is that they become more customer-oriented and cater to the more significant needs of the stakeholders, including vendors, third parties, products, and services [40]. The digital data are accessible to all stakeholders and allow users to synchronize operational decisions [41]. The other advantage of DSC is a strategic combination of human–machine interaction for designing and developing products and services in collaboration across various levels of the supply chains [42]. It helps S.C. firms to trace and improve the material flows and the value chains. This transformation from conventional to digital supply chains involves stakeholders interacting with each other [43]. That, in turn, helps the business firm in strategic decision-making through data insights from the digital ecosystem [44]. An organization's decision-making capabilities depend on lean, agile, resilient, and green operations. Companies will make specific decisions based on the absorption capabilities of the firm [45]. In a dynamic setting, decision-makers must identify the focus areas in DSCs to prioritize their efforts [46]. Table 1 exhibits the dimensions of DSCs. Based on the literature, the dimensions of DSCs to deal with disruption are as below.

Table 1. Dimensions of DSCs to deal with disruption.

Dimension	The Implication in a Disruptive Environment	Sustainable Performance	References
Agility and Responsiveness (AaR)	The responsiveness and agility enhance the firms' preparedness to deal with disruption. It will also make S.C.s responsive in post-pandemic situations.	- Helps to anticipate customer demand and optimize inventory - Helps in designing optimal supply networks - Ensures on-time fulfillment of demand	[39,46–48]
Digital Collaboration (D.C.)	Advanced technologies to collaborate with strategic partners to improve the customer and supplier experiences for reducing risk during the pandemic. It reduces cost and human contact and enhances efficiency.	- Prediction of cost fluctuations - Digital platforms for invoices and requisitions - Anticipating SC risk - Selection of best sourcing for cost optimization	[5,49–52]
Intelligent Optimization (IO)	Closed loop of combined humans and machines. It aids in appropriate decision-making for balancing demand and supply during the disruption.	- Optimized human–machine decision making	[10,50–56]
End-to-end Transparency (E.E.)	To enhance transparency throughout the S.C.s. The tracking becomes easier during stock-out situations and develops trust among the stakeholders.	- Helps in predicting demand forecasting - Avoids stock-out situations - Matching changes with customers shifting channels	[4,5,15,23, 43,53]
Holistic Decision-making (H.D.)	An integrated approach for decision-making. It enhances overall efficiency during the disruptive environment.	- Helps in performance optimization - Delivers parallel visibility	[4,54,56]

2.2.1. Agility and Responsiveness (AaR)

This was based on a review that was based on four principal facets. The usage and benefits of big data analytics to business firms and societies for the agile and responsive future supply chain have been reviewed based on 120 articles published between 2005 to 2020 across seven themes to help global supply chains to understand and cater to uncertain business environments [39,40]. The mediating role of information sharing strategy on the agile and digital supply chain has been evaluated by challenges posed due to disruptions to obtain sustainable supply chain performance in SMEs [46]. The agility supply chain has become a critical technology-centric strategic tool for digital transformation to cater to competitive pressures and strengthen operational and strategic performance. In Centobelli et al. [47], their paper reported how digital technology supports the deployment of agile supply chain management to improve sustainable development. Similarly, in other recent works the role of digital technologies to build agile and responsive supply chain is discussed [48,49].

2.2.2. Digital Collaboration (D.C.)

Farajpour et al. [5] conducted a systematic study review on the digital supply chain based on various constructs, structures, and limitations. Based on the previous works, the authors have developed a DSC framework to support processes, data, and sustainable performance. Hadduh and Khare [50] empirically investigate digitalization's potential benefits and impact on selected lean operations practices. The influence of DSC on various lean operations improvement techniques was analyzed, including, Just in time (JIT), visual management (V.M.), total productive maintenance (TPM), continues improvement practices, automation and poka-yoke practices. The study also highlights various technological trends, including 5G, IIoT, big data, and predictive data modeling. Cloud computing was perceived as a critical influencer in the digitalization of supply chains. Tao et al. [51] explained the evolving usage of digital technologies in product design, development, collaborative manufacturing, and mass customization. The various types of technologies include blending digital twin and blockchain technologies (DT-BC) (which integrate and enhance smart manufacturing), service efficiencies, and sustainable value chains. The cyber–physical integration with DT-BC builds an intelligent manufacturing environment to cater to the fluctuations in demand. In another study, Katsaliaki et al. [52] conducted a content analysis to evaluate the role of digital collaboration in reducing supply chain disruptions and resilience using digital technologies.

2.2.3. Intelligent Optimisation (IO)

Ivanov and Dolgui [10] discussed intelligence optimization using intertwined supply networks (ISN) for resilient goods and services systems. The author used dynamic game-theoretical modeling to discuss the survivability of ISNs through resilience during disruptions. Hadduh and Khare [50] discussed various technology trends in the critical areas of lean operations using empirical research to evaluate the impact of the digitalizing supply chain on lean operations and overall business performance. Recent studies utilized institutional theory and dynamic capabilities view theory to explain the theoretical framework for digital technology usage in supply chains. Katsaliaki et al. [52] evaluated past research on supply chain disruptions and resilience in supply chain design and recovery strategies using cost-benefit analysis. Gupta et al. [53] explained the firm's orientation in adopting industry 4.0 and digital supply chains. Sawik [54] discussed supply chain adopting intelligent digital technologies for factoring financing of upstream supply chains. Corsini et al. [55] developed a data-driven framework to select the optimal replenishment strategy. Priore et al. [56] applyied machine learning to the dynamic selection of FMCG supply chains.

2.2.4. End-to-End Transparency (E.E.)

Marcucci et al. [4] discussed the impact of operations and IT-related industry 4.0 on firm resilience.

Farajpour et al. [5] conducted a systematic study review on digital technologies responsible for supply chain transformation. A DSC framework for value stream to support strategies, enablers, and processes was discussed to build end-to-end transparency. Bai and Sarkis [43] explained the usage of blockchains for operational decisions and building sustainable and transparent supply chains. Further, the usage of digital technologies for resilient and sustainable supply chains during the pandemic situation is discussed in the study by de Sousa Jabbour et al. [23]. In a similar study by Ghadge et al. [15], the impact of IE 4.0 technologies on the digital transformation of supply chains using simulation modeling was discussed. In another study, Gupta et al. [53] discussed the relationship between dynamic capabilities and digital supply chain performance. Various institutional theories support the presence of digital technologies for more responsive supply chains.

2.2.5. Holistic Decision-Making (H.D.)

Marcucci et al. [4] conducted an empirical survey to investigate the impact of I.E. 4.0-based I.T. operations on the firm level of resilience. Sawik [54] analyzed the effect of the pandemic using stochastic optimization of supply chain resilience. Prindle et al. [56] explained various transformation strategies in the supply chain to evaluate the presence of IE 4.0 and digitalization.

DSCs are enabled and capitalized via a 'digital thread' that is conceived to enable the information flow related to products and services through physical and digital channels [20]. This loop is termed a 'physical-to-digital-to-physical-loop', illustrated in Figure 2.

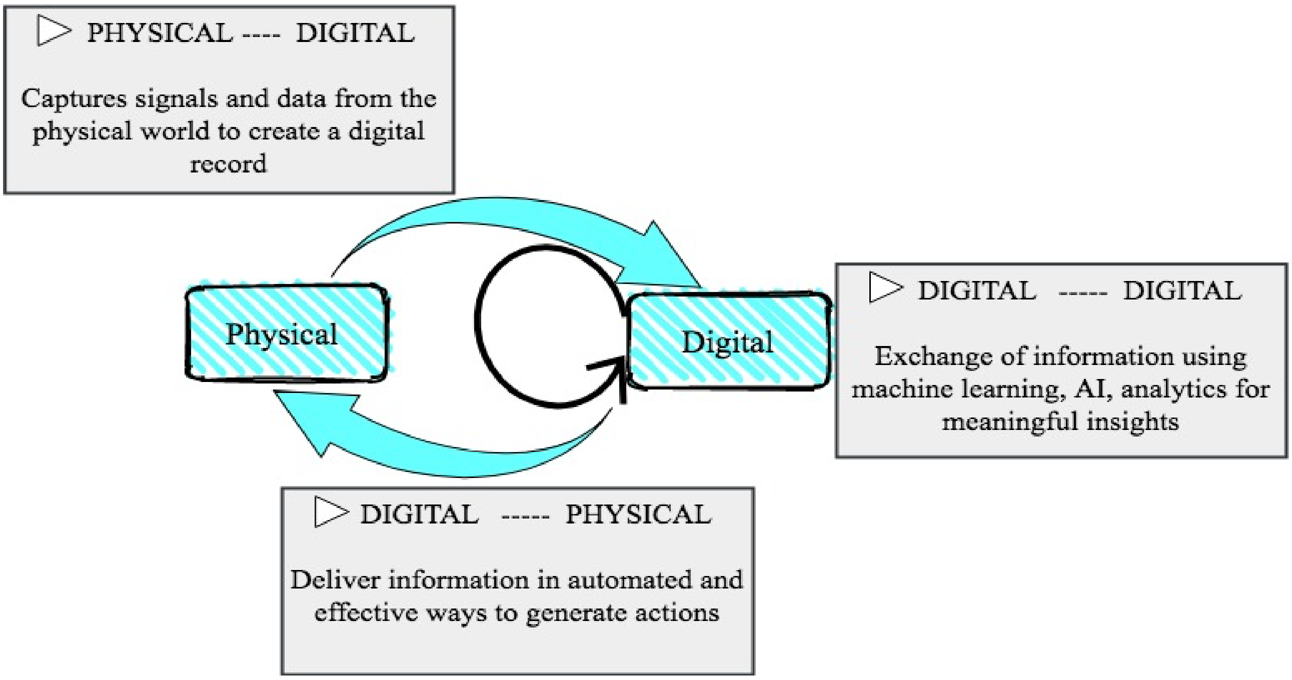

Figure 2. Physical-to-digital-to-physical-loop.

The information clusters have moved from individual units to integrated yet open systems to support transparency and innovation [57]. This digital stack of DSCs ensures seamless information exchange among all parties. The new form of DSCs incorporates interlinked nodes that are digitally integrated. The connected nodes are agile, and they are focused on dynamic fulfillment, digital development, intelligent supply, smart factory, and connected customers.

2.3. Sustainable Performance (S.P.)

I4TEs broadly change the landscape of supply chain activities with more value addition that positively influences a firm's economy. The enhancement brings dynamic development to the supply chain ecosystem. Thus, firms started realizing sustainable performance for economic and social benefits. Various tools, including the triple bottom line, became significant in evaluating the S.P. of firms [58]. DSC is evolving as a tool to generate a sustainable competitive advantage for the firm through an intelligent, autonomous, and highly responsive supplier network [59]. Various underlined technologies, including big data and additive manufacturing, are used for process integration and productivity enhancement. I4TE is a portfolio of digital technology that abides by the IPT and dynamic capability of the firm to generate sustainable business performance [60,61]. Our research discusses all perspectives of sustainable performance in light of the triple-bottom-line approach.

2.4. Supply Chain Disruptions amid COVID-19 Pandemic

The pandemic has created market shrinkage, with managers looking for new processes to maintain production levels. Notably, this pandemic has challenged organizational environmental sustainability, downsized the consumer base, and raised enormous questions for industrial management. The latest works by Govindan et al. [62] and Ivanov [10] have highlighted the devastating impact of COVID-19 on GSCs. Based on findings from this study, the S.C. network has shown poor resilience to the pandemic, with approximately 35% of manufacturers reporting S.C. network failure due to COVID-19. Thus, decision-makers have been forced to explore technological transformations to enhance agility, readiness, and resilience in their S.C.s. I4TEs have developed a framework to adopt cyber–physical integration principles in various processes, such as manufacturing, SCM, and logistics [15,22]. The pandemic has accelerated the need for real-time data to develop resilient S.C.s for the future.

BDA has provided much support in decision-making to organizations in areas such as logistics operations [57,63] and emergency operations decisions [64,65] to minimize the pandemic impact. Ivanov [42] identified the effects of disruption on S.C. responses. Additionally, recent studies suggest that I4TEs can enhance resilience and ripple effect control [10,54]. Moreover, firms with successful digital networks are better positioned during the pandemic and show a more positive indication of recovery processes [66,67]. S.C. operations are also indirectly affected by the disruption. These operations propagate through S.C. and cause a ripple effect. The study by Ivanov and Dolgui [10] shows that the ripple effect is more prevalent in GSCs with multi-tier organizational networks. To find balance, robust S.C. resilience strategies need to be built. Thus, companies are exploring solutions to predict risks and assess vulnerability to protect S.C. operations during these uncertain times. The main papers examined for this study to understand the current scenario of I4TEs, DSCs, and S.P. during the pandemic are listed in Table 2. Bier et al. [68] described a systematic study review and content analysis that has been carried out to evaluate the methods for mitigating supply chain disruptions.

Various theories and future research directions were discussed in the risk structure. Ghadge et al. [15] evaluated the impact of industry 4.0 on supply chain sustainability using simulation. Govindan et al. [62] proposed a decision support system for demand fulfillment in the public health supply chain during the disruption. The authors proposed a real-time fuzzy inference system for controlled groups. Javed et al. [69] discussed the safety concerns of automation and digitalization. The research illustrates use cases to demonstrate the interaction between autonomous machines and hazardous materials during manufacturing operations. Industry 4.0 technologies (IIoT, cloud, and fog computing) with HAZOP and fault tree analysis support flexible production operations. Sarkis [70] explained research themes for investigating sustainable supply chains.

Similarly, Kumar et al. [65] explained using digital technologies for humanitarian operations through real-time online platforms. Liza et al. [71] discussed lean production and the usage of IE 4.0 technologies for sustainable and intelligent operations to obtain sustainable performance. These studies have contributed to insights into the disruption and suggest possible solutions to develop sustainable S.C.s for the long term.

Table 2. The main contributions are focused on COVID-19 impact.

Author (s)	The Objective of the Study	Industry
[68]	To explore risk management in SCs	SC
[15]	Application of I4TEs to develop a framework for cyber–physical integration adoption	Manufacturing
[62]	Development of decision support system for healthcare S.C.	Healthcare
[10]	To predict the effect of COVID-19 on GSCs	SC
[69]	How I4Te can deal with the COVID-19 pandemic	Manufacturing
[70]	Role of COVID-19 in transition to sustainable S.C. production	Production and SC
[65]	Impact of the pandemic on sustainable production and consumption	S.C. and operation management
[71]	How pharmaceutical S.C.s sustain in the COVID-19	Pharmaceutical SCs

2.5. Research Gap

Previous studies on I4TEs have shown an essential effect on the sustainable productivity of the firm [60,71]. Additionally, DSCs provide agile, collaborative, responsive, and end-to-end visibility; the emerging, resilient S.C.s will reduce overall risk while enhancing preparedness and responsiveness to recover from the disruption [21]. DSCs overcome the limitation of conventional S.C. to support appropriate decision-making, enhance digital collaboration, and create transparency among partners in DSC. Most previous studies are analytical but lack empirical testing of the DSC impact. The studies contribute to the earlier studies on I4TEs, SCs, and sustainable performance, but the impact of DSCs needs to be explored. Additionally, earlier works were extended to compare digital technologies' performance in developing economies. As a result of the literature review, the research gaps are identified in the previous literature [72–76]. In the study, we aim to understand the role of digital supply chains in the sustainable performance of firms in developing countries and to evaluate how digital supply chains can support the sustainable performance of firms. The study discussed the comprehensive measurement framework to determine the implementation of digital technologies for sustainable outcomes.

2.6. Theoretical Underpinning and Hypotheses Development

The performance of S.C.s is vital in all types of business; this can be improved when delivered through the I4TEs application. Nevertheless, due to the complex, interconnected and intelligent network of S.C.s, it is necessary to build a framework to show inter-relationships between I4TEs, DSCs, and S.P. Galbraith [77] discussed the IPT theory to support the conceptualization of organizational structures. The theory discussed the requirement of information processing and organizational capabilities to obtain the best commercial outcomes [29]. Several areas, such as information systems [78], integration [79], S.C.s [80], and digital technologies [81] have applied this theory in the past. Based on this theory, we propose a theoretical framework that measures DSC's impact on the S.P. of the firm. The mediation effect of DSCs was assessed on the inter-relationships of I4TEs and S.P. The antecedents of DSCs for the S.P. of firms are explored from the literature, with pre-defined constructs of I4TEs and S.P. used to develop the model. Before describing the conceptual framework and hypotheses, the dimensions of DSCs are elaborated. The constructs of I4TEs and S.P. were undertaken from past research [60]. The model is extended with a new construct of DSCs to investigate its influence on I4TEs and S.P. Thus, research work uses information systems, technologies, and S.P. operations of businesses.

2.7. Industry 4.0 Technologies and Sustainable Performance

Industry 4.0 technologies (I4TEs), viz., big data analytics (BDA), additive manufacturing (AM), and the internet of things (IoT), have challenged traditional organizations to embrace them to achieve a competitive advantage, as well as interactive communication through sensors and cost efficiency [56]. I4TEs include digital manufacturing through integrating processes and digital technologies [60]. The key objective of I4TEs is to increase the productivity of an organization through a high level of automation [2,82]. Firms have assessed the adoption of I4TEs, such as BDA, AR, and virtual reality (V.R.), to simplify their manufacturing processes to enhance S.P. [18,81]. These technologies are also helpful in reducing greenhouse emissions and waste; they facilitate advanced tracking and monitoring systems that support companies to perform more efficiently from the ecosystem perspective. From a social angle, these technologies improve the knowledge level of employees and provide a safer working environment for staff [83]. IPT theory concludes that I4TE signifies the firm's capabilities of information processing that optimize decision processes to improve business performance. All these technologies directly relate to achievement and are significant in enhancing integration among S.C.s, thus resulting in sustainable organizational performance [2]. Therefore, we propose that:

Hypothesis 1 (H1). *I4TEs have a positive and direct influence on the S.P. of the firm.*

2.8. Industry 4.0 Technologies and Digital Supply Chains

Organizations are now transforming to information-based decision-making, meaning traditional S.C. is becoming obsolete [84]. I4TEs are driving the creation of interconnected systems and helping firms to re-design their structures and systems to develop transparent S.C.s [85]. I4TEs create value, flexible manufacturing, customization, and engagement, and they help measure the S.P. of an organization as an economic dimension outcome. With the help of I4TEs, real-time information sharing is available to manage resources and processes more efficiently [86–88]. These networks are known as disruptive technologies and serve as competitive weapons. The agile supplier network enhances the S.P. outcome for firms. Adopting a 'smart factory' has automated the process leading to improved accuracy and timesaving [89]. Digital development has enhanced accuracy and brought suppliers together on one platform. From an IPT perspective, I4TEs and DSCs are information-based technologies that will enhance the capabilities of any business to attain optimal performance. Hence, the study proposes a hypothesis:

Hypothesis 2 (H2). *I4TEs have a direct and positive impact on DSCs.*

2.9. Importance of Digital Supply Chains against Pandemic

The configuration of DSCs is a dynamic system that leverages I.T. to integrate S.C. activities. One key goal for developing DSCs with I4TE inclusion is a more robust integration and smoother information flow among S.C. partners using a 'physical-to-digital-to-physical-loop' of DSCs [20]. Moreover, these DSCs are a significant part of the strategy to enhance the overall performance of an organization. DSCs also support sustainable S.C. operations, along with sustainable objectives [90]. The advantages of DSCs indicated by the benefits of a platform are available to firms to enhance integration amongst their partners. Different stakeholders in an organization have different levels of performance. Thus, transformation towards adopting I4TEs and DSC can address these differing demands; adoption will reduce cost, enhance productivity, transparency, and accuracy, and it will balance demand and supply operations [91]. With DSC support, there will be communication in real-time among S.C. partners.

Furthermore, IPT theory signifies the firm's capabilities of information processing that optimize decision-making processes to enhance the S.P. of the business. From IPT theory, the effect of information processing through DSCs will be explored. The shocks and disruptions amid the COVID-19 situation provide evidence for the urgent need for DSCs to develop DSCs to enhance visibility and responsiveness [10]. Recent research has highlighted a growing opportunity for data-driven approaches to mitigate S.C. risk [25]. Moreover, response planning activities and real-time control are needed to develop resilient S.C.s for risk mitigation [68]. The last decade witnessed an increased interest by researchers in the S.P. of companies and how this can be obtained. Since the emergence of industry 4.0, firms are finding ways to achieve sustainability by shifting their focus from economic performance to becoming more socially and environmentally active. Based on recent research, it can be assumed that, to enhance the S.P. of firms with I4TEs, DSCs are needed.

DSCs were seen as the study's mediating variable for three reasons. Firstly, I4TEs always precede DSCs. The role of DSCs changes concerning I4TEs and acts as a 'dependent variable'; concerning S.P., it acts as an 'independent variable'. A causal relationship between DSC and I4TEs or S.P. exists in either case. Secondly, DSC is exerted as a mediating variable as the interrelation between the I4TEs, and S.P. is statistically significant. Thirdly, the study aims to examine the relationship between I4TEs and S.P. rather than focusing on the independent variable, i.e., I4TE. The mediated model is illustrated in Figure 3. From an IPT perspective, the DSCs build a robust information architecture that enhances the S.P. of a business [54,92]. Thus, we consider economic, social, and environmental performances as the dimensions of S.P. I4TEs have a direct effect on S.P., but the impact of DSCs is still to explored. Thus, we propose that:

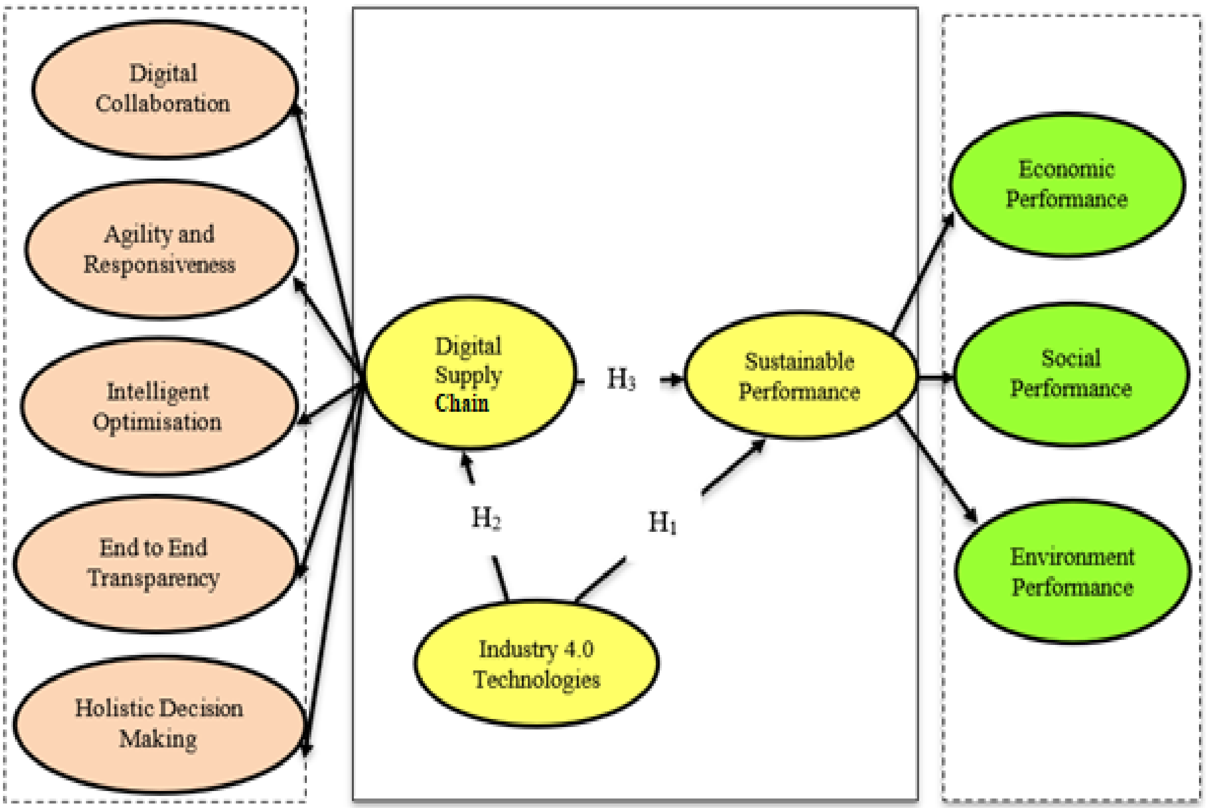

Figure 3. A proposed hypothetical structural model.

Hypothesis 3 (H3). *DSCs mediate between I4TEs and the S.P. of the firm.*

Based upon the above propositions, a hypothetical structural model has been drawn up, as shown in Figure 3.

3. Methods and Material

3.1. Survey Instrument Development

The survey has utilized primary data collection methods to determine the interrelationships among selected constructs. Based on the approach proposed by Gerbing and Anderson [93] for developing the instrument for this research, the researchers interacted with practitioners and academics. The study used multi-item measures to enhance reliability and validity and remove errors [94]. All items were adapted to capture the perceptions of supply chain managers representing different sectors concerning the role of DSCs. The five-point Likert scale was used in the study. The organizations have implemented digitization with the help of I4TEs, and measurement scales have been developed by Fettermann et al. [95] and Kamble et al. [60]. The measurement scale considered the transition phase of the firms. This study evaluated the influence of the I4TE and DSC dimensions on S.P. through the measurement model. The concept of DSCs is new and needs to be tested; hence, organizations need to be better versed in the economic benefits of this network. The data collection instrument was validated in two stages to confirm measurement reliability and validity. The first stage included an online discussion with academic and business world professionals to check the content validity of the measures. A group of seven experts was set up, including two academics in the area of the supply chain management domain, two technology industry professionals facilitating their firms during the digitalization processes with I4TEs, and three industrial domains in supply chain operations in the electronics/technology domain. The content validity ensured that the chosen measures adequately addressed the study's subject. In the second stage, a pilot study with 25 professionals with a background in the digital transformation of supply chains, and working in the I.T./electronics sector, was conducted. Table 3 elaborates on the respondents' demographic details.

3.2. Data Collection

The case location was the Integrated Industrial Estate (IIE) in North India. IIE is the hub of industries and has diverse and heterogeneous manufacturing setups promoted by state governments. As a purposive sampling, the questionnaire was shared with the professionals with a cover letter explaining the study's objective [96]. In addition, it was shared with personal contacts using the snowball approach. The contacts were also asked to circulate the questionnaire within their networks to reach the appropriate respondents. These respondents hold managerial positions and have a background in I4TEs and DSCs. Initial responses from 168 contributors were received in the first six weeks, and 34 were received in the last two weeks. No difference was detected between the responses received in the early or the later weeks. The data have been obtained from operations and supply chain professionals with the experience of more than five years. The experts include operations managers, supply chain practitioners, plant managers, purchasing managers, logistics managers, I.T. experts, and strategists. The responses were associated with different firms operating in the manufacturing, I.T., pharmaceutical, and healthcare industries. The sample of 202 respondents is regarded as adequate for such research [97].

Table 3. Demographic profile of the pilot study.

Gender	***Percentage***
Male	*74%*
Female	*26%*
Age	
20–25	*20.3%*
26–31	*38.6%*
32–37	*13.4%*
37–45	*20.3%*
Above 45	*7.4%*
Industry	
Manufacturing	
Electronic and electrical manufacturing products	*47%*
Automobiles	*15%*
Additive manufacturing	*2%*
Pharmaceutical firms	*10%*
I.T. Industry	
I.T. solutions provider	*16%*
Healthcare	
Healthcare services	*9%*
Position in the company	
Operations Manager	*31%*
Supply chain practitioner	*26%*
Plant manager	*14%*
Purchasing manager	*4%*
Logistics manager	*7%*
I.T. expert	*12%*
Strategist	*6%*
Experience	
>5 years	*33%*
Between 6–10 years	*42%*
Between 11–15 years	*18%*
More than 15 years	***7%***

4. Analysis

The relationship between DSC, I4TE, and S.P. of the firm is analyzed using partial least squares structural equation modeling (PLS-SEM) [27,98]. The study employs the PLS-SEM to predict the model [97]. PLS-SEM has evolved as a standard approach for statistically analyzing the complex inter-relations among an observed and latent set of variables. Using PLS-SEM, twenty-five items were selected in the present study, being that the factor loading of each is more than 0.70 [99]. Figure 4 depicts the measurement model, and the subsequent sections discuss PLS results.

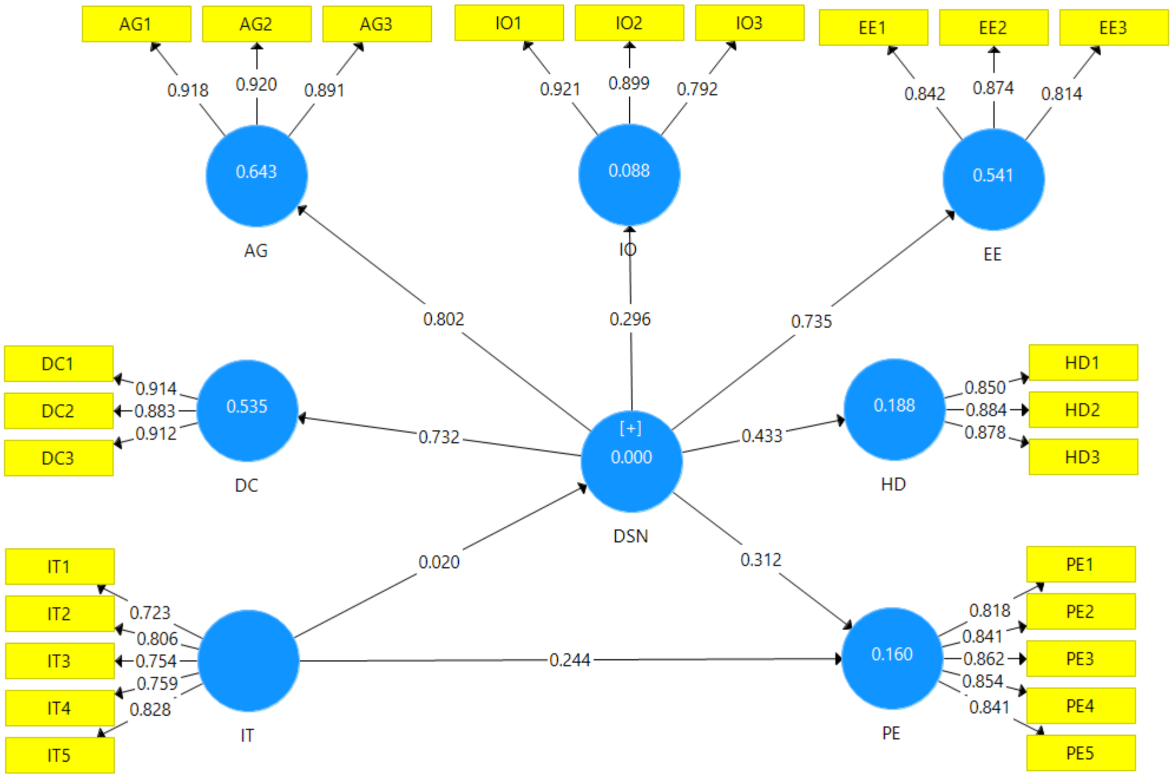

Figure 4. Full structural model.

4.1. Measurement Model

The DSC is a first-order construct, and I4TE and S.P. are first-order. The first model was established between the I4TE and S.P. to check the significant effect. DSC has five first-order constructs, namely digital collaboration (D.C.), agility and responsiveness (A.G.), intelligent optimization (I.O.), end-to-end transparency (E.E.), and holistic decision-making (H.D.). For the reliability test, Cronbach's alpha for the constructs was calculated and found to be significant.

4.1.1. Reliability

The values obtained from the model are shown in Table 4. From Table 4, Cronbach's alpha values for the constructs are AG = 0.923, DC = 0.939, E.E. = 0.821, HD = 0.862, IO = 0.867, I4TE = 0.846, and S.P. = 0.900. Additionally, composite reliability values for the constructs are AG = 0.951, DC = 0.961, EE = 0.894, HD = 0.916, IO = 0.919, I4TE = 0.885, and SP = 0.926. The values of each construct are greater than 0.70. Hence, the model is reliable.

Table 4. Cronbach's alpha, composite reliability, and AVE.

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Agility and responsiveness (AG)	0.923	0.924	0.951	0.867
Digital collaboration (DC)	0.939	0.939	0.961	0.891
End-to-end transparency (E.E.)	0.821	0.827	0.894	0.737
Holistic decision-making (H.D.)	0.862	0.865	0.916	0.784
Intelligent optimization (IO)	0.867	0.87	0.919	0.792
I4TE (industry 4.0 technologies)	0.846	0.879	0.885	0.607
Performance (social, economic, and environmental (PE))	0.900	0.906	0.926	0.714

4.1.2. Convergent Validity

This measurement denotes the degree to which the construct should provide convergence [100]. This validity can be established if all the items load significantly on their denominated latent variables. The convergent validity has been assessed through factor loading and average variance extracted (AVE). The values of factor loadings and AVE are shown in Table 4.

As depicted in Table 4, the values have exceeded the recommended values. The composite reliability values are more than 0.60 [101], and the AVE values are higher than 0.50 [102], respectively.

4.1.3. Discriminant Validity

Discriminant validity demonstrates the significance of latent variables and the square root value of AVE for individual constructs [102]. Table 5 depicts the values of discriminant validity.

Table 5. Value of Discriminant Validity.

	AG	DC	DSC	EE	HD	IO	IT	PE
AG	0.931							
DC	0.525	0.944						
DSC	0.835	0.809	0.622					
EE	0.591	0.528	0.577	0.858				
HD	0.294	0.296	0.534	0.301	0.885			
IO	0.231	0.175	0.316	0.015	0.049	0.89		
IT	−0.074	0.034	0.024	0.006	0.119	0.068	0.779	
PE	0.122	0.227	0.305	0.118	0.179	0.674	0.239	0.845

AG: Agility and Responsiveness; DC: Digital Collaborators; DSC: Digital Supply Chains; EE: End-to-End Transparency; HD: Holistic Decision Making; IO: Intelligent Optimization; IT: Industry 4.0 Technologies (I4TEs); PE: Performance (Social, Economic and Environmental).

From Table 5, it is clear that discriminant validity is achieved, since the non-diagonal values (square root of AVE) are more significant than the off-diagonal values.

4.1.4. Common Method Bias (CMB) and Non-Response Bias

CMB may inflate the proposed model Podsakoff and Organ [103]. It is used to check correlations among the observed variables [104]. The responses were split into two datasets. For checking CMB, a complete collinearity assessment approach is used in PLS-SEM. Since the values are lower than the threshold value of 3.3, the model is free from CMB.

Further, the non-response bias was calculated using the independent *t*-test and chi-square (χ^2) test. The two groups of respondents were classified as early and late respondents. No significant difference was found between early respondents (n = 168) and late respondents (n = 34). There are no significant differences between the two groups based on these results.

4.2. Structural Model

The hypothesis results are presented in Table 6 and show that I4TE has a positive and significant effect on S.P. (I.T. → S.P. (p-value < 0.05); I.T. → DSC (p-value < 0.05)). The cut-off value for determining statistical significance is 5%, as per the previous studies. As depicted in Table 6, CSR and AVE are within acceptable limits [104].

Table 6. Bootstrapping results for a structural model.

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	*t*-Statistics (/STDEV∣)	*p* Values	Significance
IT → SP	0.028	0.041	0.037	1.025	0.000	***
IT → DSC	0.257	0.257	0.055	4.705	0.001	***
IT → DSC → SP	0.420	0.420	0.049	8.495	0.000	***

*** indicates $p < 0.05$; significant.

4.2.1. Mediation Effects

The effects of I4TEs, DSCs, and S.P. were evaluated using a path model. In the second model, I4TE (I.T.) was added as a mediating variable to calculate the direct and indirect effects. The structured equation modeling method applied in the structural model is shown in Figure 4. The constructs are reflective and adapted from previous research.

4.2.2. Direct and Indirect Effects

SEM is conducted to test the effects (direct) of I4TEs on S.P. (H1) and DSCs (H2). According to H1, I4TEs positively influence S.P. and are significant. Direct and indirect effects are calculated in PLS using the bootstrapping method and indicate the following results:

The model with I4TEs, DSCs, and S.P. constructs is displayed in Figure 4. Table 6 presents the results supporting hypothesis H3, which shows a significant mediating effect of DSCs on the indirect relationship between I4TEs and S.P.

Table 7 indicates that the mediating effect of DSC was found to be positive. The mediated path I4TEs → DSCs→ SP is significant, with I4TEs and S.P. justifying 54 percent of the variance in S.P. The results from hypothesis testing reveal the existence of complete mediation in the current study; the direct effect of I4TEs on S.P. in the presence of DSCs is insignificant, whereas the indirect effect of I4TEs on S.P. is significant ($p < 0.001$). In agreement with previous studies, there is a significant and positive relationship between I4TEs and S.P. [23,60]. The current study has provided empirical validation of this relationship. The mediated path I4TEs → DSCs→ SP is significant, with I4TEs and DSCs justifying 54 percent of the total variance in S.P.

Table 7. Hypotheses.

Hypothesis	Hypothesis Statement	Sig.	Result
H1 *	I4TEs → PE	***	*Supported*
H2 *	I4TEs → DSCs	***	*Supported*
H3 **	I4TEs → DSCs → SP	***	*Supported*

* *indicates* direct effect; ** *indicates* indirect effect; *** *indicates* $p < 0.05$; significant.

5. Discussion and Research Implications

The findings advance perspectives on I4TEs and their impact on S.P. and supply networks. The research is a novel contribution through empirical research on the digital ecosystem and its influence on the S.P. of firms. The current study contributes to the adoption of advanced I4TE and SCM by considering the strong impact of DSCs, and it is pioneering in measuring the impact of DSCs using IPT theory. The research verifies that digital supply chains can enrich the S.P. of firms through real-time responsiveness and highly collaborative ecosystems. The findings help to better understand the expansion of DSCs into a more reliable and robust system that improves the S.P. of firms when I4TEs are involved. Previous studies have shown inconsistency in their conclusions on the relationship between I4TEs and S.P. Some research works have shown that I4TEs influence operational performance [72], environmental performance [73], and sustainable manufacturing [74], leading toward S.P. [75]. The business value of DSCs has also been investigated [76].

The study discusses the influence of DSCs on the relationship between I4TEs and S.P. Thus, the current study enriches the literature on technology adoption using a framework, bridging the gap previously identified in recent work. Another research implication lies in confirming the direct influence of DSCs on S.P. This result is consistent with previous studies [76,105]. Some studies have previously discussed how DSCs influence the S.P. of a business [72,74].

This study highlights the importance of DSCs for sustainable business performance. COVID-19 has raised concerns over the preparedness of the S.C.s of businesses; therefore, there is a need to explore new ways to develop resilience throughout the marketplace [106]. DSC facilitates communication and information exchange that will bring resilience and sustainability to their overall performance [78]. The current study empirically validated that I4TEs directly and positively affect a firm's performance. The research findings have proven the significant relationship between I4TEs and the S.P. of firms [74,81]. With COVID-19 being highly infectious, it is difficult for the market to operate as before. This study has shown that DSCs and I4TEs can enhance S.P.; hence, firms should develop intelligent and resilient S.C.s by embracing new technologies. These technologies will help manage operations with maximum efficiency and minimum human contact with products. With the inclusion of I4TEs, firms can reduce cost and waste, minimize errors, create a safer environment for the workforce, and forecast, with greater accuracy, inventory anticipation. The application of technologies will also help develop a robust S.C. network [107,108]. I4TEs with agility can influence DSCs to recover from this disruption. COVID-19 has badly disturbed the logistics and transportation industries, and thus the flow of goods is difficult to trace. With the help of DSCs, traceability and information sharing among S.C. partners will enhance. The pandemic has affected the S.C. infrastructure and will consequently affect trade relations; thus, firms need to focus on developing sustainable S.C.s for the long run. Trading conditions caused by COVID-19 demand collaboration among S.C. partners to operate their businesses faster and more efficiently [10]. It will help reduce the impact of the pandemic on S.C. trade relations. Digital collaboration with stakeholders sharing a common platform for exchanging information enhances transparency through the S.C. network, saving both cost and time, ultimately leading to improved overall business results. This dimension of DSCs develops a connected community to enhance S.P. [40]. The pandemic will affect firms' ROI (return on investment) in the long term; hence, cost reduction is necessary for companies. Cost reductions are possible with support from DSCs and I4TEs [109]. Additive manufacturing uses real-time information to develop customized products, to build highly transparent internet-enabled manufacturing, and to constantly improve the service operations and overall supply chain cost [110].

5.1. Theoretical Contributions

Based on the previous works, underpinning theories are drawn from information processing theory (IPT), which primarily supports the argument that an economic system can enhance a firm's efforts to channel digital resources for sustainable business performance and the enhancement of quality and capability [28,29]. This research offers significant theoretical implications regarding the DSC literature, and its impact on the sustainable performance of a business firm is supported by I4TEs. The study has multiple theoretical contributions. Firstly, the paper reviewed the digital supply chain management and industry 4.0 literature and symmetrically engaged in knowledge creation based on information processing theory (IPT). This pioneering study focuses on the information processing need of the business firms that can be achieved with I4TEs and DSC.

Secondly, various theories have been developed and adopted in DSC research. Out of the available theories, this is the only theory-based research focused on the relevance of digital supply chains to analyze their sustainable performance. IPT has proven to be the most compelling theoretical framework for DSC research. By extending the information processing capability in their DSC, firms can obtain sustainable performance. The study offers novel insights into how integrating DSCs and I4TEs can support a firm's sustainable performance (S.P.). Overall, the study has revealed the impact of DSC on the I4TE and S.P. of the business firm. It focuses on three constructs (2 first-order and 1 s-order), with direct and indirect effects. The results show the significant impact of DSC on the indirect relationship of I4TE and S.P. of the firm, which confirms the mediating nature of DSC. This finding extends the previous research, where I4TE directly affects the S.P. of the business firm, thereby setting an imperative for the inclusion of DSC with I4TE to enhance real-time information exchange and collaboration across S.C.s.

Thirdly, the study suggests that DSC is competent in dealing with the pandemic situation and may drive the firms toward achieving resilience, agility, and survivability.

Finally, the research has extended IPT theory to explore the capabilities of DSCs and their significant impact on the firm's performance. Information processing in real-time can deal with disruption and volatility. Based on earlier research, the current study has demonstrated that DSCs significantly enhance S.P. in a volatile market [111]. As DSCs are dynamic and integrated, real-time information and analytics can reduce the limitations of linear S.C.s, where visibility and collaboration were restricted due to problems of integration, alignment, and transparency [37,112]. DSCs overcome those limitations of linear S.C.s by supporting collaborative decision-making and flawless data transfer. They can revolutionize work on information management and integration among S.C. partners. Thus, they can enhance the performance, along with I4TE, in contrast to the previous research by Kiel et al. [113], Delongate et al. [114], and van de Wetering [115], which claimed the negative influence of I4TE on the performance and enhancement concerning environmental problems. This research is the first attempt to look at DSC from the information processing perspective, which has significant implications for DSC research in general.

5.2. Managerial Implications

The study has notable inputs for supply chain practitioners to understand better the significance of DSCs for designing resilient supply chains.

5.2.1. Integration of Digital Supply Chains and Industry 4.0 Technologies Facilitates Strategic Decision-Making

DSCs and I4TEs are information-based technologies that enhance any business's capabilities to attain optimal performance. DSCs provide synchronized planning, integrated decision-making, and provide dynamic fulfillment that transform strategic decision-making, whereas I4TEs create value, flexible manufacturing, customization, and engagement and help measure the organization's sustainable performance. Organizations can deploy DSC networks for future expansion and business diversification. Each area of strategic planning is addressed by DSCs, which produces a variety of considerations. DSCs allow organizations to change their strategies; they can compete across each supply chain node simultaneously instead of focusing on a single area.

5.2.2. The Dynamic Digital Core of Digital Supply Chains Overcomes the Fragmented Business

COVID-19 has badly disrupted the supply chain (S.C.), so the flow of goods is difficult to trace [115]. The conditions caused by COVID-19 demand collaboration among S.C. partners to operate their businesses faster and more efficiently. With the help of DSCs, traceability and information sharing among S.C. partners will be enhanced. DSCs help organizations track material flow, arrange schedule synchronization, achieve demand-supply balance, and monitor financial transactions. The interconnected network of DSCs may enhance transparency during the pandemic because each sub-system is aware of any other node at any time.

5.2.3. Digital Supply Chains May Build a Resilient and Sustainable Supply Chain for the Post-Pandemic Situation

The supply chain needs to become resilient to survive in a post-pandemic situation. Adopting dynamic business practices through advanced, interconnected, and intelligent networks of DSCs and I4TEs can be a productive solution to developing a robust and resilient S.C. The DSCs may help supply chain managers make appropriate and cost-efficient decision-making using real-time data. The SC partners can communicate and decide in real-time, thus addressing fluctuating demand, dynamic pricing, falling productivity, and enhancement in transparency.

5.2.4. Competitive Differentiation Can Be Achieved through Digital Supply Networks

With DSCs, substituting for materials or connecting to low-cost sources for buyers is more accessible than directly reducing the raw material cost. The 'cost of quality' is also reduced as visibility and monitoring are enhanced, and sensor-based systems identify any errors and drive process improvements. The capabilities of supply DSCs, such as 'enhanced asset efficiency' and 'click-to-ship,' bring the right combination of strategy, innovation, technology, and operations to develop digital and innovative S.C. business models. DSCs can act as game changers.

5.2.5. Developing Supply Chain Responsiveness for Proactive Risk Mitigation

DSCs enhance responsiveness during a period of disruption. Regardless of geographical boundaries, increased connectivity enables a rapid response to natural disasters, artificial crises, or any other disruption. The COVID-19 environment has forced the market to accept the significance of responsiveness and transparency, which are needed to help firms proactively assess risk and prepare them to respond quickly to changing customer and market demands. Responsiveness also supports firms in meeting shareholder expectations during difficult times.

5.2.6. A Boon to the Healthcare Sector Amidst COVID-19

DSCs can improve healthcare S.C.s and ensure that healthcare companies send the proper medication to suitable patients at the right time. Real-time data are used to predict the seasonal demand for medication, where a virus is spreading, and locations to be targeted, and it allows hospitals to arrange distribution channels where they are most needed. Hospitals can also reduce the likelihood of poor outcomes due to error and variability.

6. Conclusions, Limitation, and Future Scope

6.1. Implications to Theory and Practice

Our study triggers interest in exploring specific factors that drive the effective implementation of DSCs to reduce the risk amid the uncertainty caused by natural disasters by drawing the perspectives of other organizational theories (institutional theory, stakeholder theory, resource base view, and organizational citizenship behavior), technology adoption theory, technology acceptance model (TAM), and the unified theory of acceptance and use of technology (UTAUT), which complement each other to advance perspectives of sustainable digital supply chains. Future studies can be extended to other geographies to validate and generalize the findings.

6.2. Key Lessons Learned

This study advances deliberations around DSCs, I4TEs, and S.P linkages. The pandemic has created an opportunity for organizations to transform their S.C. networks into DSCs. These DSCs help develop agility, collaboration, responsiveness, end-to-end visibility, and resilience. This development is not limited to any specific industry; it is the need of all businesses. The main aim of DSCs is to reduce S.C. risk and enhance preparedness and responsiveness for any disruption. Thus, DSCs will improve the S.P. of a firm by developing resilient S.C.s. The present study discussed that DSCs mediate I4TEs that benefit the business's S.P.

DSCs can provide synchronized planning, integrated decision-making, dynamic fulfillment, intelligent factories, and digital procurement with a high level of transparency that will help organizations become more resilient during a disruptive phase. These DSCs offer a competitive advantage to firms focusing on sustainable goals. The pandemic has raised a question about the survivability and sustainability of the S.C.s of many firms. The post-pandemic situation needs preparedness, agility, and responsiveness in S.C.s; these need to be built right now, and to enhance S.P., the introduction of DSCs may act as a catalyst. Thus, for agile, intelligent, responsive SCs, DSCs need to be implemented along with I4TEs.

6.3. Limitations of the Research

The study of this scope has a few limitations. The first limitation is the digital technologies studied, as most DSC-adopting firms are in the initial implementation stage and have yet to have the final results to analyze the new system's efficiency.

Data collection was conducted during the pandemic, limiting contact with contributors; regulations have meant that it has not been possible to organize an onsite visit for insights into the firms involved. The research can be expanded across other industries, and the case study approach can be used in future research. The professionals' responses are based on their experience, current needs, and future requirements. Secondly, the respondents belong to diversified work environments, such as FMCG, product designing, and I.T. services. The heterogeneous response demography may help in developing industrial cases. Thirdly, there was limited access to onsite visits due to COVID-19 restrictions. Besides all limitations, the current study has yet to consider the effects of the size of each firm. Thus, future studies can focus on exploring its moderating effect on developing DSCs in different-sized companies. Future studies may consider research questions exploring the role of management commitment towards realizing the need for digital technologies in manufacturing and service industries amidst the pandemic situation and suppliers' organizational commitment to adopting DSCs.

6.4. Future Research Directions

Future studies can integrate multiple organization theories to extend this research's scope further. In developing countries, firms need to acquire more understanding of the benefits of DSC to gain momentum and to improve supply chain performance, using organizational theories, including IPT and neo-instutotional theory. In addition, a variety of studies can be carried out on industry 4.0 technologies and their influence on supply chain functions. Besides, the adoption capabilities of firms towards industry 4.0-enabled supply chains (supply chain 4.0) can be evaluated on the basis of resources using a resource-based view and TAM theory. Besides, the industry 4.0 implementation presence can be evaluated in terms of the supply chain's performance based on various parameters (namely, information transparency, sharing capabilities, operational flexibility, responsiveness, etc.). Additionally, the strategic dimension of deploying supply chain 4.0 or DSC can be evaluated based on the diffusion of innovation and its impact on improvement in production capabilities and performance of supply chain processes. Other verticals of IE 4.0 technologies usage in other functional domains of the supply chain, including procurement 4.0, smart manufacturing, logistics 4.0, and warehouse 4.0, can be discussed based on the present study's findings.

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Appendix A

Industry 4.0 technologies I4TEs (IT)
The organization has implemented/OR is 'in transition phase' of implementation of IoT in S.C.s.
The organization has implemented/OR is 'in the transition phase' of implementing BDA in S.C.s.
The organization has implemented/OR is 'in transition phase' of CC implementation in S.C.s.
The organization has implemented/OR is in a transition phase of implementation of AM in S.C.s.
The organization has implemented/OR is 'in transition phase' of implementation of A.I. in S.C.s.
Digital Collaboration (D.C.)
The SC firms do information exchange using real-time data exchange.
The organization is collaborating/will collaborate to manage synchronized data across the S.C. network.
The organization is communicating/will communicate seamlessly across networks with suppliers, partners, and customers.
Agility and Responsiveness (A.G.)
The organization is using/will use sensor-based data to become agile and responsive.
The organization is able/will be able to manage S.C.s during disruption through digital supplier networks.
The organization immediately responds/will respond to any uncertain situation without latency.
Intelligent optimization (I.O.)
The organization is using/will use hybrid humans and machines together to make spot decisions.
The organization is able/will be able to take proactive actions.
Internet manufacturing enhances the optimized use of resources among S.C. partners.
End-to-end transparency (E.E.)
The DSC enhances S.C.'s visibility.
The DSC enhances S.C. traceability.
The digital supplier networks provide financial benefits to the organization.
Holistic decision-making (H.D.)
The organization used DSC for decision-making and performance improvement.
The organization is able/will be able to obtain financial objectives through the decision making.
The organization can/will be able to mitigate organizational risk using DSCs.
Sustainable performance (S.P.)
The organization has reduced costs, including procurement, inventory, production, etc.
The organization has enhanced return on investments.
The organization has improvised the sustainable product design and reduced consumption of hazardous materials.
The organization has improved the working conditions of the firm, focusing on employee health and safety.
The organization has reduced gas emissions and waste.

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