Sustainable Performance through Digital-Supply-Chains in Industry 4.0 Era

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Contributor: Sudhanshu Joshi , Manu Sharma

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

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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 [1][2][3][4][5]. The sustainability perspective of systems needs to be understood, and thus, organizations are exploring new technologies that might help them succeed [6]. 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 [7]. 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 [8][9]. 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. Digital Supply Chains (DSCs)

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 [10][11]. Straub [12] 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 [13][14]. 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 [14]. The digital data are accessible to all stakeholders and allow users to synchronize operational decisions [15]. 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 [16]. 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 [17]. That, in turn, helps the business firm in strategic decision-making through data insights from the digital ecosystem [18]. 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 [19]. In a dynamic setting, decision-makers must identify the focus areas in DSCs to prioritize their efforts [20]. **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	[13][20][21][22]
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	[23][24][25][26][27]

Dimension	The Implication in a Disruptive Environment	Sustainable Performance	References
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	[25][26][27][28] [29][30][31][32]
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	[17][23][29][33] [34][35]
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	[30][32][33]

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realizing sustainable performance for economic and social benefits. Various tools, including the triple bottom line, became significant in evaluating the S.P. of firms [36]. DSC is evolving as a tool to generate a sustainable competitive advantage for the firm through an intelligent, autonomous, and highly responsive supplier network [37]. 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 [38][39].

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. [40] and Ivanov [28] 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 [34][41]. 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 [42][43] and emergency operations decisions [44][45] to minimize the pandemic impact. Ivanov [16] identified the effects of disruption on S.C. responses. Additionally, recent studies suggest that I4TEs can enhance resilience and ripple effect control [28][30]. Moreover, firms with successful digital networks are better positioned during the pandemic and show a more positive indication of recovery processes [46][47]. 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 [28] 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. [48] described a systematic study review and content analysis that has been carried out to evaluate the methods for mitigating supply chain disruptions.

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

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

Various theories and future research directions were discussed in the risk structure. Ghadge et al. [34] evaluated the impact of industry 4.0 on supply chain sustainability using simulation. Govindan et al. [40] 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. [49] 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. Sharma et al [50] explained research themes for investigating sustainable supply chains.

Similarly, Kumar et al. [45] explained using digital technologies for humanitarian operations through real-time online platforms. Liza et al. [51] 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.

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