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Managing Supply Chain Resilience and Sustainability Concerns with Industry 4.0: A SSM-based Approach

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Abstract

The combination of trade-policy shocks and COVID-19 disruption has exposed vulnerabilities that require rethinking for managing of global supply chain (SC). Businesses are forced to realign their global supply chains to maximize efficiency, and profits along with decisive actions on social and environment sustainable practices. The capability of Industry 4.0 for societal sustainable benefits and support for creating a resilient supply chain is a matter of research importance. The dynamic paradigm shift and interconnections of resilient and sustainable practices for managing SC have not been investigated in the literature and practitioners in emerging economies are still struggling for implementation. This paper attempts to integrate these two streams, identify issues faced by SC actors, and develop a conceptual framework for managing them. The study has two parts; the first literature review and interviews held with apparel SC stakeholders to identify complex supply chain issues post-COVID-19. Later, soft system methodology (SSM) was used to structure the research to understand resilient and sustainable issues in the system thinking, CATWOE analysis to identify root causes, and design a conceptual framework for the final implementation model from multiple functional domains expert perspectives. This paper proposes an emerging Industry 4.0 technology framework including cloud-computing applications and artificial intelligence (AI) tools to manage key issues faced for building a resilient and sustainable supply chain in the apparel sector. This research findings reveal the framework consisting of three main components criteria system, delivery system, and Industry 4.0 AI-enabling system to manage sustainable practices adoption and resilient performance challenges.

Keywords

Resilience, Sustainability, COVID-19, Supply Chain, Industry 4.0 AI, Soft-system methodology (SSM)

Introduction

The Global supply chains faced widespread disruptions as the COVID-19 outbreak, caught many companies off-guard interrupting nearly 97% of firms globally and putting them in a difficult position to handle unprecedented supply chain (SC) challenges (Majumdar et al. 2020; WHO 2020). The modern supply chains are considered the central nervous system of our economy and society (Ivanov 2020), the COVID-19 pandemic brought to light critical vulnerabilities and fundamental flaws in global supply chains, prompting the need for improvements (Crane and Matten 2020; Gereffi 2020; Golan et al. 2020; Golgeci et al. 2020). In addition, the trade war between the US and China and restrictions on exports of raw-material supplies and products created uncertainty about the future of free trade.

Businesses can no longer take it for granted that current tariff commitments enshrined in the WTO rules will prevent sudden protectionist surges, particularly as the WTO dispute-settlement mechanism has stopped functioning (Baldwin et al. 2020).

Post-COVID-19 sustainability got into sharper focus than ever before having exposed vulnerabilities across governments, trade, and industries. Global SC necessitated extensive partnership, enhanced efficiency, and adaptability, adopted sustainable environmental and social practices, and reduced ambiguity among the suppliers of raw materials to the final consumer with risk mitigation strategies during disruption (Dohale et al. 2023). Additionally, in 2021 business leaders showed up in force in Glasgow at the UN Climate Change Conference (COP26), pledging to take on the challenge of reaching net-zero goals by 2050. Thus, industries are on the spot to lay out credibly how they will deliver a transition while building and reinforcing resilience against the certain unpredictability of ongoing economic and political shocks (McKinsey Report 2022).

Apparel industry is considered as an important industry in most developing countries and due to the complex nature of global supply chains, it has faced enormous SC disruptions and social impact due to COVID-19 (Chowdhury et al.2017). Apparel industries are exceedingly competitive and are also considered as a huge profit margin sector. The contribution of the apparel industry to developing economies like India is significant. This industry plays an important role in the Indian economy as it contributes 4% to the GDP and 14% of the total earnings of India through exports of apparel products (Dohale et al. 2021; Majumdar and Sinha 2019). However, due to the impact of the COVID-19 outbreak on the global supply chains, the exports of readymade garments from the Indian apparel sector reduced by 91.04% during April 2020, which caused a massive financial loss (AEPC 2020). This has prompted industry and academia to design sustainable and resilient SC while ensuring they are competitive and leveraging the benefits of the Industry 4.0 AI era. Realizing the need to mitigate the impacts of the pandemic, researchers have already focused on developing mitigation strategies for retrieving sustainable operations, economic restoration, and adaptability of SCs in the context of the COVID-19 pandemic disruption (Chowdhury et al. 2021; Rahman et al.2021). Though these studies present valuable insights into SC challenges and mitigation strategies during the pandemic on a global scale, there has been less focus on a comprehensive and holistic approach to studying SC resilience and sustainable (RS) challenges together, involving various SC stakeholders' views and perceptions from a particular industry (Negri et al 2021).

According to Jabbarzadeh et al. (2016) with the arguable importance of sustainability and resilience integration, few studies have been exploring this research area Thus, the study is done to understand post-pandemic RS issues of apparel SC from various actors' being in the system but having individual perception and ideas to counteract the challenges. These issues are real-world problems that are not structured and are complex. Reid et al. (1999) explain how to study and analyze these real-world problems using Soft System Methodology (SSM). SSM has been denoted as a suitable technique used to deal with soft problems by considering the human factor. The conceptual framework and final possible solution through Industry 4.0 support for managing RS issues are explored. It provides probable solutions to the problem issues, so we refer as a key premise of applying SSM in this study. This leads to developing research questions such as, what resilient and sustainable issues characterize the complexity for SC in times of uncertainty in the Industry 4.0 AI era and to what extent SSM can assist in understanding the issues from actors and managing these issues, as it helps to provide the inputs from the real world and supports to identify the possible solutions with human activity system.

Based on the research questions, research objectives are developed as follows;
To identify resilient and sustainable issues in the apparel supply chain post-COVID-19
To develop a conceptual framework and provide appropriate solutions for managing the apparel SC for RS issues post-COVID-19 disruption

This study can contribute a lot to existing literature **(**Negri et al. 2021) because it will provide a better understanding of the combined RS issues for the apparel industry SC post-COVID-19 in emerging economies. Moreover, this study has great implications, even from a practical point of view, because it will help decision-makers prepare an effective plan for implementing sustainable and resilient business practices in their organizations. The remaining paper is organized in the following sequence: Section 2. discusses the literature on, SC resilient and sustainable interconnected issues post COVID-19, the role of Industry 4.0 in SC resilient and sustainability, SSM-related literature, and research gap; Section 3. explains the SSM Methodology Section 4. Application of SSM to study the resilient and sustainable issues and map issues, identify root causes, build conceptual model and final implementation model. Section 5. has

theoretical discussions and managerial implications. Section 6. Conclusion, limitations, and the future scope of research.

2. Literature Review

A comprehensive literature review was done of the available literature published in journals, articles, websites, annual reports, and industry reports to study the interconnectedness of resilience and sustainability, Industry 4.0 advanced digitalization for managing RS issues, and soft system methodology-based literature.

2.1 SC Resilience and Sustainability Interconnection and their Issues post COVID-19

Earlier supply chains were expected to improve their sustainability performance for the triple bottom line (Ahi & Searcy 2013); later they had to address increasing vulnerability and uncertainty (Ali, Mahfouz, & Arisha 2017). Moreover, the concept existed that supply chain resilience is more responsive and adaptable to the changing market and sustainability acknowledges profitability; however post-COVID-19, the emphasis shifted towards achieving environmental and social goals more than economic goals (Darvishmotevali, et al.2020). Some studies argue that sustainability is a resiliency antecedent (Gouda & Saranga 2018; Jain et al. 2017) and that sustainability practices may positively enhance resilience (Bag et al. 2019).

Adaptability in uncertainties can be framed as a reinterpretation of resilience in today's unpredictable dynamic and complex social-ecological supply chain systems. Resilient practices improve sustainability in the supply chain and ultimately contribute to achieving a competitive advantage was demonstrated by (Shin and Park 2019). While Sauer *et al.,* 2021 explain that the adoption of SC resilience approaches depends on how sustainability is embedded. It is generally thought that resilient and adaptable individuals, organizations, and supply chains are, by definition, likely to be sustainable, a view supported by the work of (Fam et al. 2017). The increasing need for resilience in the design of sustainable supply chains and sustainability in the design of resilient supply chains can be observed from the recent literature (Ivanov 2021; Zahiri et al. 2017; Sauer et al. 2021; Negri et al. 2021). When integrating the two research streams, many studies now recognize the importance of integrating sustainability and resilience (Rajesh 2018).

Adoption of the SC resilience approach in the planning depends on how sustainability is embedded (Sauer et al., 2022). Hence, an integrated framework can define the future of supply chains by carefully obtaining trade-offs in the principles, and practices of business and adopting Industry 4.0 technology (Ivanov et al. 2021, Belhadi et al. 2021). The COVID-19 outbreak clearly shows the necessity of a new perspective in apparel SC operations (Ivanov and Dolgui 2020; Ivanov 2021). RS issues are to be approached holistically supporting each other for future SC management (Sauer et al. 2022; Kamalahmadi and Parast 2016; Shinghry and Rahman, A. 2018). The major integrated resilient and sustainable factors identified through the literature review and with industry expert and senior academician interactions are; responsive and infrangible contracts; adaptability and flexibility; operational capabilities and efficiency; and collaboration and strategic partnership that are elaborated as below;

2.1.1 Responsive and infrangible contracts

Inadequate information and response in SC increase the risk during disruption which has a ripple effect (Christopher and Peck 2004) causing incorrect decisions, increasing the inability to plan forecasting, and analyzing the post-disruption situation (Pettit *et al.* 2019; Shankar *et al.*2009; Rahman et al. 2021), thus challenging the resilience of the system. Information sharing and responsiveness among the supplier, manufacturer, and brand were evaded and deliveries were impacted (Van den Adel *et al*. 2022). The dominant power of brands was the primary responsible for sustainable issues of the layoffs at the upstream level of SC (Majumdar et al. 2020). The government's response and representation to buyers' countries for canceled orders and payment evasion required quick action to overcome the economic and social impact in the upstream SC. According to AEPC Report (2020), loose partnerships that did not fulfill the contracts were major SC issues post-COVID-19.

2.1.2 Adaptability and Flexibility

The disruption during the COVID-19 pandemic made businesses adapt and diversify their products, manufacturing capacities, raw material suppliers, and logistic partners (Deloitte 2022). Environmental, social, and governance are on top of customers' and end-consumers' minds, and environment regularity is evolving at international and domestic level posing difficulties the supply chain management strategies (Islam et al. 2023). Further brands increased focus on sustainability – social and environmental for vendor selection requires quick adaptation and infrastructure compliance by manufacturers in the developing economies. Lack of adopting superior technology with new

operational techniques, and govt support, and incentives hinder in making the apparel products cost-competitive globally. Munim et al. (2022) mention lack of training, causes the inability to identify and be sensitive to disruptive situations to respond on time. Multiple production route paths need to be defined and multi-operation requirements to a work center to cater to the speed and delivery (Ngai et al. 2012)

2.1.3 Operations capabilities and efficiency

Post-COVID-19 efficiency in terms of reduced raw material wastage, sustainable measures in wastage treatment, e-commerce capabilities, and productivity became critical and the capabilities had to be innovated to salvage the crisis (Majumdar et al. 2020). The three most critical operational issues for apparel manufacturers are providing healthcare safety facilities to the workforce, bringing previously outsourced activities in-house, and ensuring smooth delivery of existing orders. Further, the United Nations strong implementation of SDGs forced brands and governments to focus on a sustainable and circular economy, due to which brands have seriously adopted environmental and social sustainability under the law for their upstream SC partners to align at earliest with huge investments (Luthra *et al.*2013; Gunasekaran et al.2015; Majumdar *et al.* 2020).

2.1.4 Collaboration and Strategic Partnership

To increase resilience and lower risks, several academics have underlined the significance of collaboration across supply chain partners (Dubey et al. 2020; Scholten et al. 2019; Nguyen et.al. 2019; Le, P.B. 2021) Collaborations and mistrust on business commitments among SC partners were affected due to failed payment or canceled order abruptly (Mandal et al. 2016). The issues apparel manufacturers dealt with, including simultaneous supplier failures and price escalation, production capacity restrictions, demand uncertainties, brands canceling orders, and non-acceptance of shipments, resulted in significant collaboration issues among the supply chain partners post-COVID-19 (Ivanov 2020; Ivanov *et al.*2014). Thus, issues of strategic partnership and collaborative approach require strong contracts using intelligent business systems for mitigating future disruptions and working on environmental and social outcomes.

2.2 Role of Industry 4.0 in SC resilience and sustainability

In this section, a literature review on the integration of Industry 4.0 into the supply chain which has gained significant traction over the years has been carried out. Industry 4.0 has been gaining momentum across the globe as it promises resiliency through efficiency, reduces costs, and improves productivity and sustainability (Marinagi et al. 2023; Patidar et al. 2023; Tortorella et al.2022). Introduction of Industry 4.0 technologies such as mobile applications, artificial intelligence (AI), internet of things (IoT), blockchain, machine learning, 3D Printing, additive manufacturing and advanced robotics have changed the nature of the workplace environment in the industry and the way supply chains are managed (Munim, Z. H, et al. 2022). Recent AI advances offer novel avenues to address these SC complexities where AI-driven solutions have gained importance in business domains like process automation, tools for data analysis, and support in decision. Saberi et. al. 2019; Giannakis et al.2019; Kadambi, B. 2020) have proposed innovative solutions such as blockchain to improve supply chain visibility, traceability, and responsiveness. Table I mentions literature related to Industry 4.0 and supply chain resilience and sustainability management

For building resilience in manufacturing, AI algorithms can streamline production schedules, reducing lead times and minimizing costs (Nayal K. et al. 2022). Techniques like predictive analytics and scheduling algorithms have shown to improve production line efficiency (Tortorella, G. et al. 2020) and supply chain data can be analyzed to optimize logistics, supplier evaluation, and distribution (Giannakis et al. 2019). This leads to improved responsiveness and agility in the supply chain (Belhadi et al. 2021). Further to enhance transparency and traceability, AI tools are used for ensuring compliance with ethical standards and can assist in reducing the risk of social exploitation and environmental issues (Dubey et al. 2020). Industry 4.0 AI offers a promising solution for building and promoting more resilient and sustainable supply chains (Belhadi et al. 2021; Tortorella, G. et al. 2020; Saberi et al. 2019).

Table 1. Industry 4.0 AI-related research for RS management

Author	Industry 4.0 Related Article Description
Saberi et. al (2019)	The author research submitted on blockchain technology and its relationships to sustainable supply chain management
Belhadi et. al (2021)	Manufacturing and service supply chain resilience to the COVID-19 outbreak was explained using lessons learned from the automobile and airline industries
Munim, Z. H et. al. (2022)	The measures implemented by export-oriented readymade garment firms in an emerging economy during COVID-19 were assessed and proposed for the use of digital technology
Giannakis et al. (2019)	A cloud-based supply chain management system: effects on supply chain responsiveness
Kumar V, Vrat P, Shankar R (2022)	Explored the factors influencing the adaptation of industry 4.0 for sustainability in manufacturing firms
Ngai E. W. T et al. (2012)	Proposed the decision support and intelligent systems in the textile and apparel supply chain for supply chain performance
Chowdhury M.M.H., Quaddus M (2017)	A multiple objective optimization based QFD approach for efficient resilient strategies to mitigate supply chain vulnerabilities: The case of garment industry of Bangladesh
Nayal, K., Raut, R., Priyadarshinee, P., Narkhede, B.E., Kazancoglu, Y. and Narwane, V. (2022)	Exploring the role of factors that influence the adoption of artificial intelligence in managing agricultural supply chain risk to counter the impacts of the COVID-19 pandemic
Tortorella, G., Fogliatto, F.S., Gao, S. and Chan, T.-K. (2020)	Contributions of Industry 4.0 to supply chain resilience has been identified
Dubey, R., Gunasekaran, A., Bryde, D.J., Dwivedi, Y.K. and Papadopoulos, T. (2020),	Blockchain technology for enhancing swift trust, collaboration and resilience within a humanitarian supply chain setting.

2.3 Literature related to Soft System Methodology (SSM)

Soft System Methodology (SSM) is an established systems-based approach, developed as a way to use system concepts in (social) organizations for making interventions and understanding their efforts (Checkland & Poulter, 2006). SSM is being used in many research domains and studies of complex situations (Nurani et al. 2018; Ngai et al.2012; Shankar et al.2009) involving stakeholders and suggesting improvements in the existing system. SSM is concerned with unstructured or ill-structured problematic situations where there is no consensus among stakeholders (Sgourou et al. 2012)

SSM is broadly a qualitative research methodology that is mature, rigorous, and well-established, used in a variety of contexts, disciplines, and countries, and relies on resilient principles (Checkland and Poulter 2006). SSM is based on the System Theory Approach and involves the Human Activity System (Calvo-Amodio 2019) and is concerned with unstructured or complex problematic situations where objectives and activities are vague and involve human interactions. According to Shankar et al. (2009), a typical SSM consists of seven steps. Figure 1. illustrates Checkland's (2000) seven-stage overview of the SSM.

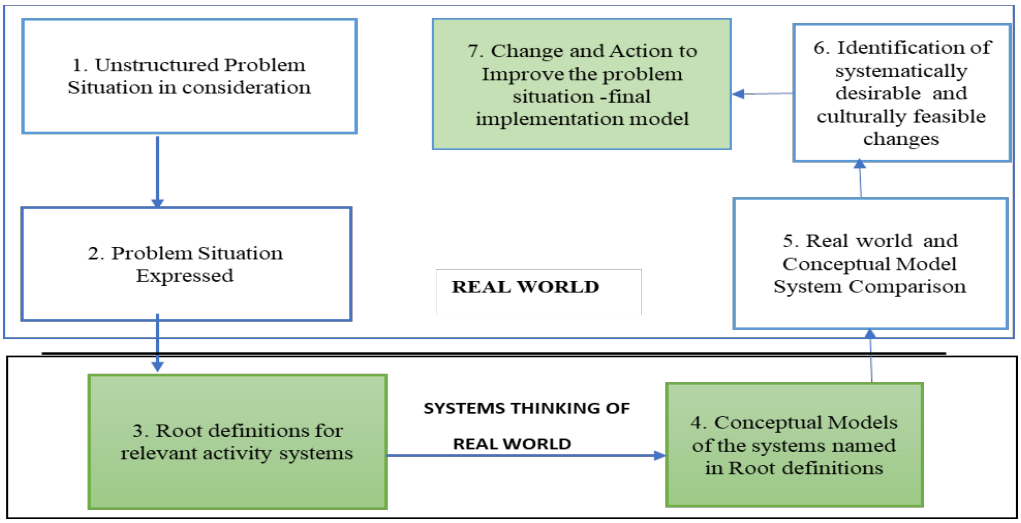

Figure 1. SSM Seven Steps Processes of Checkland's

It analyzes unstructured problems using techniques of symptom maps, rich images, root cause analysis, root definition, final implementable models, and conceptual models, emphasizing systemic thinking and addressing underlying issues. Critical to the soft system methodology, CATWOE facilitates the analysis of intricate issues through its emphasis on Customers, Actors, Transformation, Worldview, Owners, and Environmental Constraints. This approach guarantees an inclusive comprehension of the matter from multiple points and contextual elements. SSM involves qualitative approach to enable the researchers to explore issues within their context, reveal stakeholders' diverse views, surface underlying assumptions and encourage stakeholder participation (Wang et al. 2015). Few of prior studies undertaken by multiple researchers that specifically examine the uses of soft system methodology are as mentioned in Table 2.

Table 2. SSM related research

Areas of SSM based studies	Research done to explore
Industry 4.0 Implementation challenges and strategies	Kumar, V et al. (2024) proposes an Industry 4.0 framework to manage the key implementation issues using soft system methodology (SSM)
Industry 4.0 and Logistical Challenges	Sarkar et al. (2023) utilized SSM to dissect significant port logistical difficulties, offering insights into solutions in the context of Industry 4.0,
Food Security Challenges in the Public Distribution System	Gupta and Shankar (2023) the study investigated food security challenges within the Indian public distribution system, employing SSM.
Explore sustainability in higher education	Paucar-Caceres et al. (2022) employed SSM to explore sustainability in higher education, emphasizing the roles of key stakeholders in formalizing action networks to achieve Sustainable Development Goals (SDGs).
Designing Intelligent Supply Chain Model of Natural Fibre Agroindustry	Nurhasanah et al. (2020) this study intended to apply a soft system methodology approach in designing an intelligent supply chain model of natural fibre agroindustry
Application of Soft Systems Methodology in the Sugar Industry	Gerwel Proches and Bodhanya (2015) SSM is applied to the sugar industry that is characterized by diverse stakeholders having multiple and competing objectives
Stakeholder Identification	Wang et al. (2015) to identify pivotal stakeholders at all organizational levels applied soft system methodology and stakeholder theory
Textile Manufacturing Management	Ngai et al. (2012) This study has harnessed SSM to uncover management support system opportunities in textile manufacturing energy and utility utilization.

Through the literature, it reveals that only a limited number of research papers employ systems thinking methodologies like SSM, in the context of supply chain management, operations management, and Industry 4.0. However, have not dealt with the pressing issues of the combined problem of sustainability and resilience in the Industry 4.0 digital era, especially in the context of are real problems faced by actors in the supply chain post-COVID-19.

2.4 Research gap

This section provides the background of our study by summarizing integrated RS issues and how they are linked to earlier research work though both are rarely studied together in relation to the industry practice, and their linking is available in few kinds of literature (Pettit et al. 2019; Sauer et al. 2021; Chowdhury et al. 2021; Negri et. al. 2021). There is still lack of knowledge on practices that can simultaneously improve supply chain sustainability and resilience Negri et. al, (2021). Further, in the developing economy context, there is nearly no paper that focuses on soft system methodology with interconnected resilient and sustainable aspects that have become inevitable for business and of research importance.

The literature review identified the need to study SC resilience and sustainability aspects in a holistic approach particularly post-COVID-19. Supply chain with the adoption of Industry 4.0 digital tools to manage resilience and sustainability issues requires investigation from the real-world system. Furthermore, exploring the issues post-COVID-19 is an attempt for future strategies as there exists a complex problem among the SC stakeholders, struggling in their limited functional area wanting to build SC capacities post-pandemic. With the complex nature of the apparel supply chain wherein many actors form a part of the larger body, the SSM is the unique model that can deal with human interaction and bring in the perceived ideas into a more systematic conceptual model and compare with the real-world issues to find possible solutions faced individually. The study attempts to brings together important actors together and aims to achieve the objective and uses the findings to help practitioners to understand the potential issues and challenges in formulating and implementing strategies for resolving these issues. This paper introduces an SSM-based approach to analyze managing challenges of integrated sustainable and resilient in order to be transformed into the real-world Industry 4.0 digitalized apparel supply chain, filling a research gap in the existing literature.

3. Methodology

3.1 Soft System Methodology -SSM

Qualitative research tools used in SSM in an interactive manner, to facilitate the comprehensive insight, which is .

Table 3. SSM Research

Sr. No.	SSM Stages	Description
1	Unstructured problem situation in consideration	Describing roles of apparel SC actors and problematic aspects related to resilient and sustainable issues in the real world
2	Problem situation expressed	The Rich picture is designed to express the problems and collecting inputs and information on the root causes of the system
3	Formulation of root definition from systems activities	Formulation of the root definitions and uses CATWOE analysis for classifying the actors into certain categories.
4	Conceptual Model of the systems named in the root definitions	Conceptual model is developed depicting real RS problems derived from root definition
5	Comparison of the models and real-world	The developed conceptual model is compared with the real-world situations which involve comparing it with key players having different ideas and contrasting views to provide a feasible solution with criteria, delivery and enabling system
6	Recommendation Changes that are systemically desirable and culturally feasible	Explores the desirable and feasible changes for developing ideas Industry 4.0 AI tools to be applied in the real world
7	Probable actions to improve the problem situation	Final Implementation model is developed to achieve the desired objectives with Industry 4.0 AI-enablement

intended by SSM and used as a basis to facilitate identifying the issues in the apparel SC and advocate the continuity of holistic considerations. The method employed in this study was according to that designed by Checkland (2000). Table 3. presents the research stages of this study

3.1 Data Collection

The studied industries formed part of larger research with the involvement of representatives from the apparel export council, industry associations, brands, manufacturers and raw material suppliers, mainly fabric suppliers, because individual perspectives differ, a broad range of stakeholders were considered to gain a comprehensive insight (Luna-Reyes et al. 2005). Some stakeholders participated in more than one interview and workshop, whereas others were available only for one interview. Mainly large apparel manufacturers, suppliers and brands representatives were interviewed because of their importance and diversity in the SC activities and interactions. Small-scale exporters and suppliers, IT service providers, logistic providers, and apparel industry representatives were also included in the study to facilitate a holistic view. The data collection was composed of three phases, comprising stakeholder interviews and workshops. Between 10 and 15 stakeholders participated in the workshops.

The authors have compiled empirical evidence through academia, research, and apparel industry bodies to identify the challenges and present them to the stakeholders. A workshop was held to prepare a more systematic study of the issues for identifying the problems. Later, the initiative to develop a comprehensive framework using the SSM process for systematically identifying resilient and sustainability issues post-pandemic through interaction with SC actors in the Indian apparel export-industry. In the final stage of SSM discussion held with senior industry experts on these issues addressed by actors and how a robust system for managing these issues can be developed and implemented was deliberated and proposed using Industry 4.0.

4. Results and Discussion

4.1 Application of SSM for SC resilient and Sustainable Issues post-COVID-19: Indian perspective

Adopting SSM for the Indian export-oriented apparel industry SC with Industry 4.0 digital technology manifestation is depicted through the flowchart in Figure 2. As shown the flowchart, it consists of 2 phases; the first phase consists of identifying the issues through a literature review from the Scopus database and field visits to major apparel industry. Later in the second phase interviews were held with various actors including the apparel manufacturing industry, fabric suppliers, logistic providers, industry associations, and brand offices. The resilient and sustainable issues for Phase 1 act as inputs for Phase 2 of the SSM process for studying the complex problem faced by the actors in the SC.

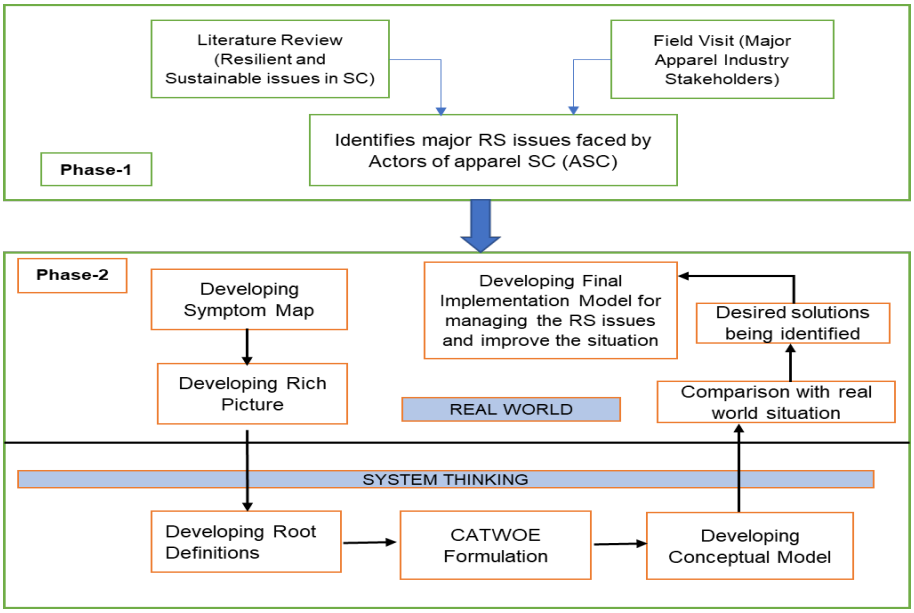

Figure 2. Flowchart for adopting SSM for identifying RS issues in the supply chain

4.2 Developing symptom map -problem situation analysis

The symptom map is the unstructured representation of the issues, which needs further analysis. In the case of the Indian apparel supply chain, a demonstration of the SSM is explained to the managers during the field visit. They are asked about the issues faced in areas of responsiveness and infrangible contracts, flexibility and adaptability, operational capabilities and efficiency, collaboration and strategic partnerships, in their daily interactions. Discussions held to build a symptom map on "what" RS issues faced, what are their concerns, and why they have those concerns. These issues were represented in the symptom map. Figure 3 represents the symptom map.

The apparel SC comprises of complex process and involves many factors like; sustainable product design, customization, fast fashion, operations flexibilities, collaborations, social-environmental compliances, financial contracts, and coordination issues between global brands, manufacturers, suppliers, regulators, logistic partners and others in the entire upstream and downstream of SC members, that are considered for the study. The COVID-19 pandemic has disrupted and challenged the SC networks and requires realignment for sourcing of material, stronger information flow, manufacturing capabilities and adaptabilities to new products and norms, effective coordination, social-environmental commitments, and stable contracts for robust supply chain management. The symptom map represents the problems faced by different actors. Post-COVID-19 issues faced by manufacturers, suppliers, and brands in the SC are the readjustment for new sustainable product design, augmented prototype, factory capacities and capabilities, and manufacturing with minimized emission and waste management, social security and inventory management issues; canceled orders, and financial stress.

Similarly, issues between the logistic providers, and manufacturers and brands are the rising shipping costs; higher cost of containers, lack of technological infrastructure for tracking and traceability of products. Further, in the developing economy like India apparel exporters, suppliers and regulators faced major labor crises, social protection of the workforce, unsold inventory and brands reducing their buying frequency, posing challenges to manufacturer, forcing to shift to online selling platforms and adopting digital technologies for forecasting and supplier selection. Similarly, each actor of the apparel supply chain endured different issues related to sustainability practices and making resilient operations at each linkage.

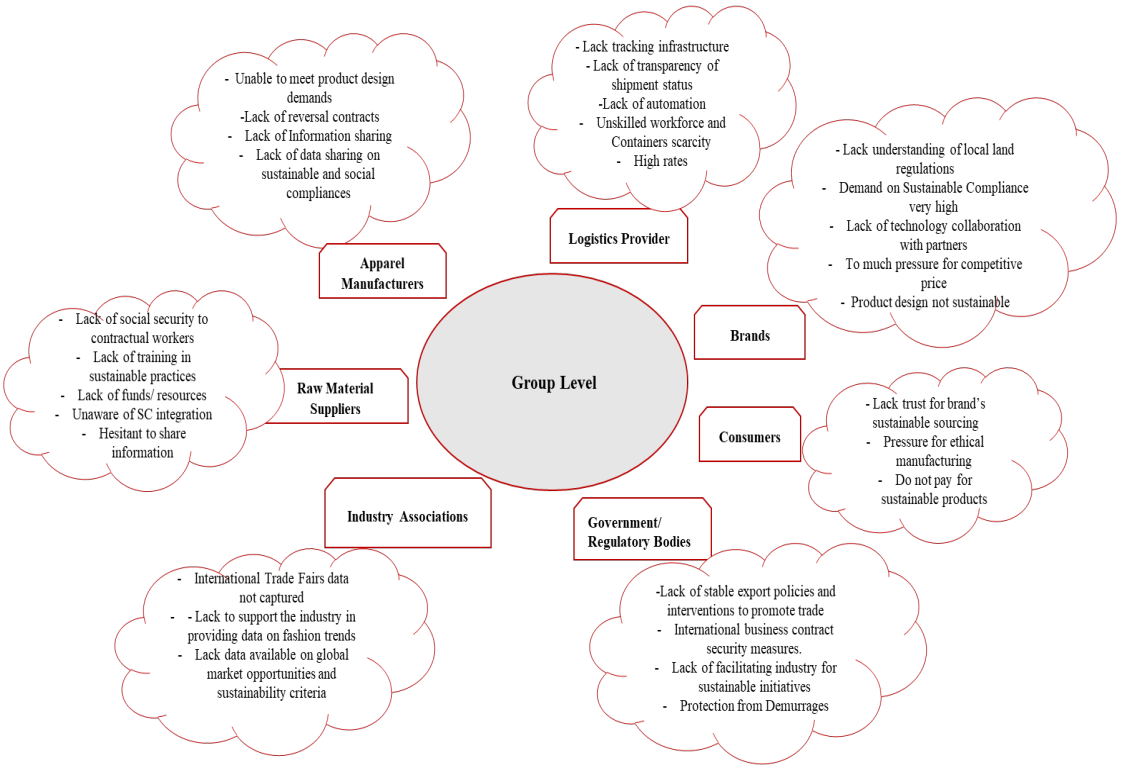

Figure 3. Symptom Map

4.3. Problem situation expressed

The analysis of the previously identified symptoms for RS challenges faced by SC managers helps us in identifying the conflicting areas. These issues were presented to five expert groups and based on their expertise and knowledge the issues are represented in a structure way; the unstructured symptoms are represented in a more structured manner. Figure 4 shows the rich-picture diagram based on the symptom map analysis.

The apparel SC as a whole suffered challenges in operational, social issues with disruption in raw material, logistics, delivery delays, government regulations, security norms and labour issues, non-acceptance of shipments and financial losses. Post COVID-19 brought the need to drastically transform with greater prominence on social, environmental and technology aspects at every stage of the apparel SC. For better understanding let us consider the case of brands and try to study the challenges faced by the brands because of the apparel manufacturer and logistic provider followed by the issues created by the brands themselves. The brands face issues due to the delayed delivery and lack of information at the level of manufacturer and exorbitant rates by the logistic companies. Like the brands faces issues with apparel manufacturer, their issues like responsible manufacturing complying with social and environmental sustainability parameters, adequate information sharing, inventory management and sustainable product design, are conflicting issues. Similarly, during the logistic provider phase, various issues encountered are traceability, delay in transportation due to lack of automation, higher rates charged and warehouse vacancies.

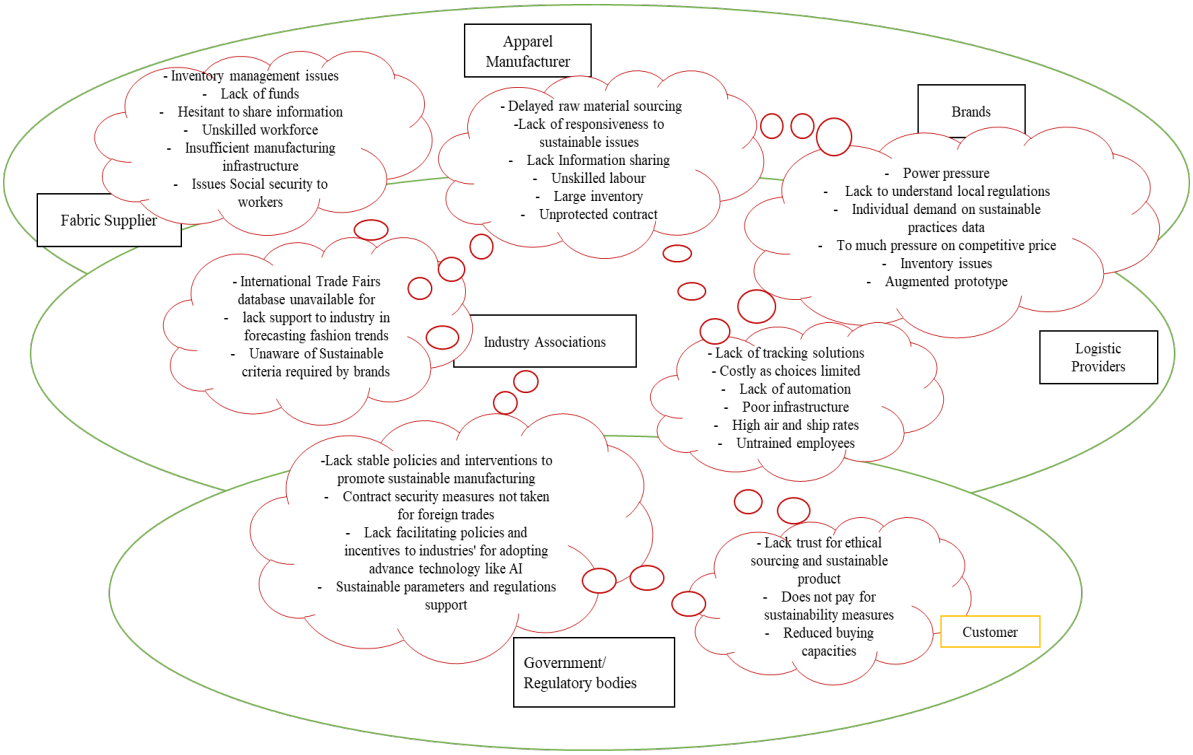

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Figure 4. Rich-picture

However, the brands are not only responsible of facing challenges; they are also problem creator. They are responsible for demanding competitive prices, inadequate technology support to upstream SC members, and high bargaining power. While the raw material supplier, a 3 tier entity in the SC, is facing issues in itself with a lack of resources and funds to meet the sustainable requirements of the global brands, lack of financial credit and government taxes, lack of social security, and does not trust sharing information with high competitiveness. Hence, collaboration is impacted due to lack of trust, operational capabilities are not optimized due to financial constraints, and government regulations related to duties and taxes. Additionally, skilled workforce, technology infrastructure, and operational capability are few challenges

The remaining steps of the SSM methodology involve the formulation of a conceptual implementation model and the identification of possible improvements in the current problematic situation.

4.4 Developing root definition

The root definition formulation is carried out by identifying the solutions to the problem situation under consideration. Before defining the root definitions, alternative root definitions and major root causes are to be identified. It is done with the help of the senior managers and expert group; here analysis of the problems is carried out to find various root causes of the problem. Four major root causes were identified: 1) lack of collaboration 2) operational challenges; 3) logistics infrastructure challenges; and 4) inadequate information-sharing platform. We have represented four root causes for RS issues along with the problems faced by different actors, as shown in Table 4.(APPENDIX-A). A CATWOE analysis has been performed to classify the processes and actors into certain categories. It helps in understanding the problem situation and its worldwide applicability.

4.5 Building the CATWOE Formulation

This stage of SSM is about conceptualizing purposeful human activity systems that are considered relevant to the problem situation and, when compared with reality, can lead to the selection of meaningful, improved interventions. The CATWOE formulation is carried out which is the mnemonic tool developed to analyze the problems faced, what are we trying to achieve, identifying possible solutions to corresponding issues, and their impact on actors. The core purpose of the activity system as a transformation process is expressed by root definition.

Based on the identified root causes, four alternative root definitions are developed as below;

1. Real-time information sharing can enhance transparency and responsiveness among stakeholders
2. With flexible operational capabilities and effective sustainable practices apparel SC can minimize environmental issues and enhance revenue
3. With infrangible collaboration among facilities and strategic partnership technology incorporation, the apparel SC can effectively deliver societal benefits and enhance ethical trade.
4. With traceability system through data sharing, information and computing capabilities, sustainable product can reach the end consumer, thus supporting visibility and trust in the value chain

These alternative root definitions were responsible for encompassing the broader characteristics of the identified root causes. For developing an appropriate root definition, all the alternative root definitions were tested against the CATWOE. The classification based on the CATWOE formulation for the Indian apparel export-oriented SC context is given in Table 5.

Table 5. CATWOE analysis of RS issues in apparel SC

CATWOE Elements	Descriptions
Customer (C)	Consumers, manufacturer, brand retailers, suppliers,
Actor (A)	Representatives of apparel Industry, brands, associations, IT service and logistic providers, regulatory authorities,
Transformation (T)	Technology enabled processes + infrangible agreement between buyer-manufacturer-supplier + web-based product traceability + sustainable business practices + active participation of Industry association and regulators, to transform into a sustainable and resilient apparel SC withstanding disruptions like COVID-19.
Weltanschauung (W)	Globally consumers are demanding sustainable and ethically produced products, which can be achieved through CAD product design, adopting business intelligence systems, adopting industrial engineering in manufacturing, and data information and computing for product traceability, and digital technology for RS capabilities to manage uncertainties and produce sustainable apparels
Owner (O)	Apparel Export Promotion Council/ Regulatory, Industry Associations, Sustainability Apparel Coalition (SAC) of brands
Environment (E)	Fast-fashion, financial and digital technology disparity across SC

The alternative root definitions were tested against the CATWOE, and the final root definition is identified. Figure 5 shows the root causes along with the alternative root definitions that are tested against the CATWOE and final root

definition is defined as "*Apparel SC can have enhanced capabilities for a resilient and sustainable management using Industry 4.0 AI-enablement which can deliver to customer's satisfaction".*

4.5 Development of the Conceptual Model

In this step, the conceptual model is developed with a structured set of activities required to implement the root definition. The final root definition for developing the conceptual model is " *Apparel SC can have enhanced capabilities for a resilient and sustainable management using Industry 4.0 AI-enablement which can deliver to customer's satisfaction"*, which acts as the guiding principle for identifying the broad parameters for developing the conceptual model. It comprises a limited number of activities to achieve the desired objectives. The developed conceptual model cannot be validated like other models that represent real-world behaviour. The model explains the concept behind the system rather than the real-world situation or system. To ensure whether the system has its fundamental properties, it requires the conceptual models to be checked (Checkland, 2000). Figure 6 represents the conceptual model developed for resilient and sustainable SC using Industry 4.0 AI tools for post-COVID-19 challenges. The initial conceptual model consists of three subsystems: 1) Criteria system; 2) Industry 4.0 AI-enabled system; and 3) Delivery system.

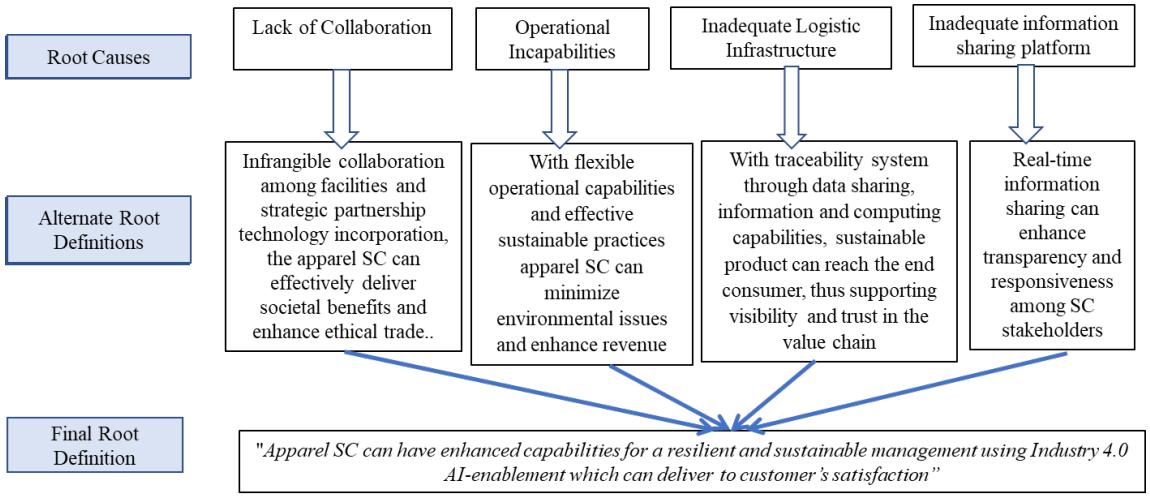

Figure 5. Alternative root definitions

In the developed conceptual model, main objective of the delivery system is the ability to deliver efficient and sustainable apparel product to the end customers with visibility and trust. A robust delivery system backed by advanced technologies, secured information sharing, product traceability, and building strategic partnerships among SC partners and proper regulatory support can deliver on time to the customers' satisfaction. For an effective delivery system, there has to be a criteria system, which is required for controlling and monitoring the overall system as per the guidelines of the regulatory bodies. Through effective collaboration and coordinated actions through cloud computing and AI can provide global competitive advantage for the apparel SC. The delivery system and the criteria system are connected to Industry 4.0 AI-enabled system. Ghobhakloo. M et al. (2023) mentioned that Industry 4.0 AI-enabled system with appropriate digital infrastructure and use of advanced technology can build a resilient and sustainable SC.

The interdependence of stakeholders and the need for transparency, trust, and effective communication highlight a resilient and sustainable SC and can be effectively achieved using Industry 4.0 tools like RFID sensors, biometric systems, customer relationship management (CRM), product lifecycle management (PLM), ERP, 3D, CAD, and AI-powered Internet of Things (IoT) systems and cloud computing regulatory support, block chain enabled SMART contracts, GPS enabled real-time tracking of goods throughout the supply chain. Data analysis to monitor and predict potential disruptions, making it possible to control the impact. AI combined with blockchain technology ensures transparent and secure tracking of transactions among the SC partners. AI has emerged as a transformative force in the apparel supply chain, offering enhancements across various facets from forecasting to ethical considerations (Islam, M. S., et al. 2023).

4.6. Comparing models with reality and proposing change.

The conceptual models developed in the previous stage serve as a means to a debate regarding the changes that would improve or resolve the problem situation that are considered desirable and feasible. The developed conceptual model is compared with real-world situations, and apparel SC stakeholders are involved to have different views and ideas that contradict the proposed concept. During the continuous review process, directions and suggestions are received for making the system progressive and adaptable for feasible improvements that are appropriate to the apparel sector. Different views were accommodated and a list of several changes was finally drafted by the workgroup, in order to discuss their desirability and feasibility with top management, managers and employees who would take the final decisions. When these models were perceived as being truly relevant to the problem situation, then the changes derived from their comparison to the perceived reality can be considered as systemically desirable. These changes are further regarded as meaningful within a given sector's culture; hence they are also considered culturally feasible. In formulating proposals for changes, an accommodation between conflicting interests was achieved

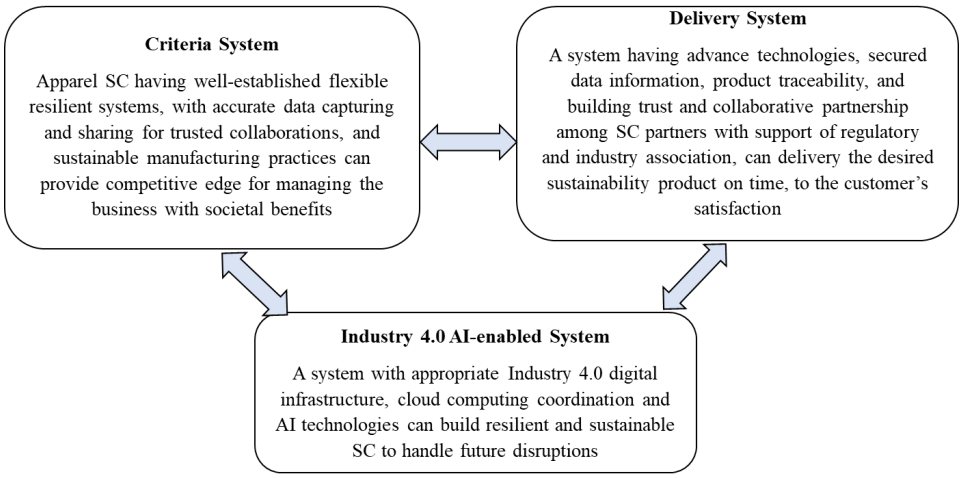

Figure 6. Conceptual model

In the next step, the developed conceptual model is compared with various real-world scenarios and situations.

.4.7 Development of final implementation model

The formulation of the final implementation model was done with inputs and direction to improve the complex problem situation as suggested in the previous steps. The final implementation model provides a series of steps, with clarity, to be taken for enabling and control the system to get the final delivery system. In this stage, after the identification of problems at the level of manufacturers, suppliers, brands, logistic providers, regulators, and industry associations, they play an important role in solving the issues for resilient and sustainable SC practices post-COVID-19. The implementation model consists of three subsystems: 1) Criteria System; 2) Delivery System; and 3) Industry 4.0 AI-enabled System. Industry 4.0 AI-enabled systems can play a major role in dealing with disruptions, providing traceability for sustainability practices through systematic data capturing, ensuring information exchange that are affordable and compatible with web-based e-portals and SC management software platforms, Internet of Things (IoT), cyber physical systems, ERP, CRM, and PLM, enabling traceability and real-time information sharing for managing issues of resilient and sustainable SC. Further, integrating the roles of regulators, apparel industry associations, and logistic providers with compatible AI technology adaptation with suppliers, manufacturers, and brands into the delivery system can enhance collaboration, strategic partnership and trusted information sharing among upstream and downstream SC partners.

The final implementation model is presented in Figure 7. The criteria system requires for monitoring and control post COVID-19 a well-established system that shall ensure prediction of demand/ supply and inventory management, quick response to SC partners, flexibility with manufacturing, trusted collaboration among various actors for managing SC resilient and sustainability capabilities in times of disruptions. As shown in the final implementation model, the delivery system has eight areas where the necessary transformation is required based on the criteria system. Hence, the Industry 4.0 AI-enabled system can support the eight identified areas of a delivery system: efficient response to

customers, collaboration, and building strategic partnerships. Industry 4.0 contribution is for delivering data-centric functions such as process monitoring, training, quality information and communication, and visibility. Industry 4.0 AI tools will deliver more dependent but consequential resilience functions such as supply chain responsiveness, operational capability, and sustainability management.

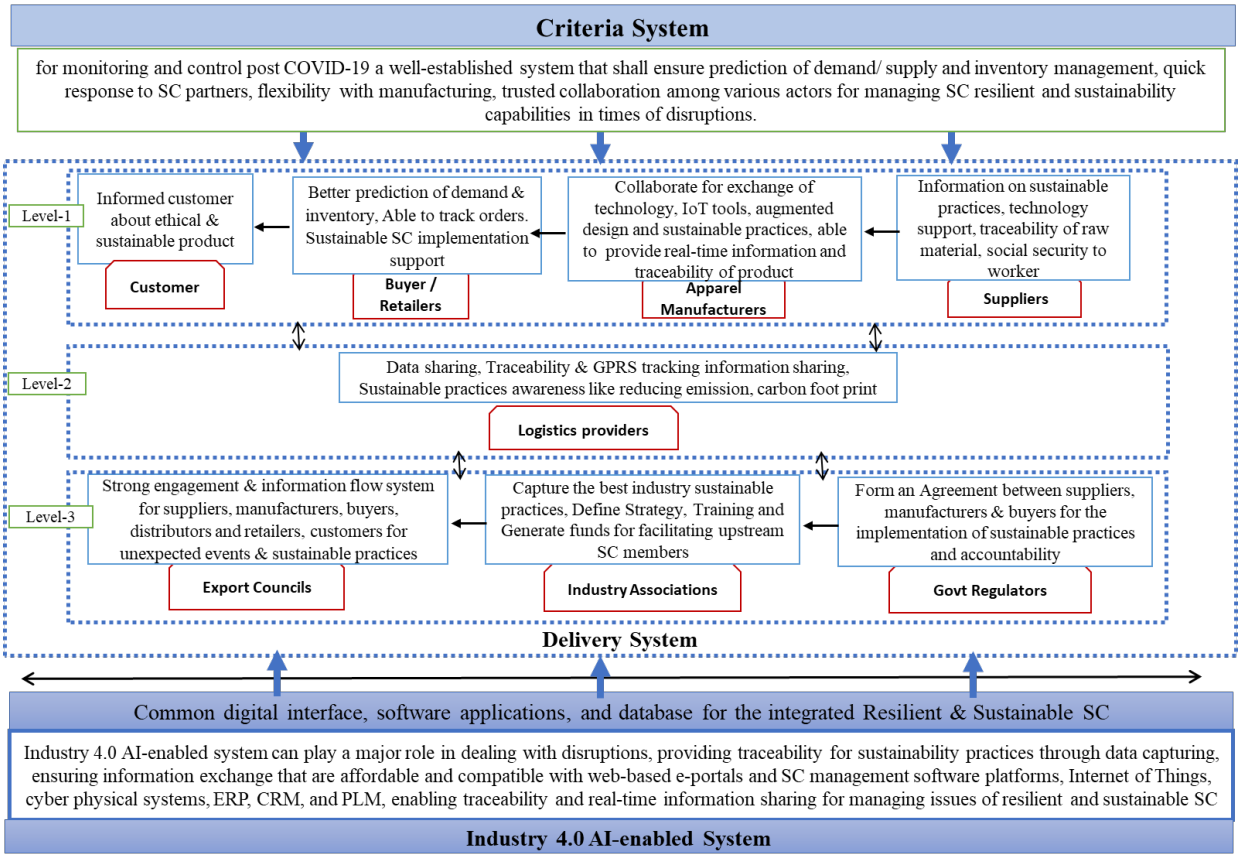

Figure 7. Final Implementable model towards resilient and sustainable SC

The robustness of the developed model was verified with the help of experienced stakeholders including the Vice President of the multinational apparel manufacturing industry with 30 years of experience, the Chairman of the industry cluster in Delhi, an EC member of the Apparel Export Promotion Council, the Senior Manager of international brand with 25 years of experience in the organization's global sustainability, and the Senior Manager of an IT company providing digital solutions to apparel industry with 15 years of experience. Post-COVID-19 the apparel sector has to align with the "new normal" resilient capabilities and adopt the desired sustainability practices enforced by brands and governments as business policy.

5. Proposed Improvements

5.1 Theoretical contribution

The research provides a unique approach to understanding the RS issues and challenges faced by actors in the apparel SC post-COVID-19 era. It can also act as a benchmark for emerging economies, as the issues faced in India, one of the major exporters of apparels, are similar that faced by other to developing economies with inadequate infrastructure, collaborative issues and financial constraints for technology adoption. This is unique in the sense that, probably for the first time, Industry 4.0 AI perspective has been considered for both resilient and sustainable issues together for the SC in the post-COVID-19 era.

This study uses SSM to develop a framework for mapping the RS issues for the Indian apparel export industry SC post-COVID-19. A comprehensive list of issues was identified from the literature review and interacting with SC

stakeholders facing challenges post-COVID-19 in data sharing, information security, operation flexibility, sourcing, transportation, deliveries, skilled workforce, and collaboration. These identified issues act like SSM symptoms that were analysed to identify the root causes. These root causes helped in developing alternative root definitions that were tested against the CATWOE analysis and the final root definition was conceptualized. The conceptual model with the subsystems; Criteria system, Delivery system, and AI-enabled system was used to develop the final implementation model. The final root definition was " *Apparel SC can have enhanced capabilities for a resilient and sustainable management using Industry 4.0 AI-enablement which can deliver to customer's satisfaction".*

The final implementation model provides an effective system to manage SC resilient and sustainable issues with the best possible monitoring, controlling, and evaluation of the delivery system. Thus, the study showed the competency of SSM in facilitating an in-depth understanding of the complexity of the resilient and sustainable issues in the apparel supply chain. The competency of the methodology to highlight the connectedness between issues and the relevance of soft issues was outstanding. Furthermore, the usage ensured that a holistic inquiry was conducted involving multiple actors of the apparel SC. There is growing interest in employing technology to enhance SC resilience and sustainability many actors have proposed innovative digital AI-driven solutions to improve supply chain visibility, traceability, and responsiveness.

5.2 Managerial Implications

Considering the emerging issues and challenges for SC post-COVID-19, it is imperative to evolve a comprehensive and all-encompassing strategy that factors in various inter-linkages and dimensions of the crisis. This study helps bring apparel SC actors' individual unstructured problems into an organized form and systematically develop a framework. The study gives a reflective understanding of the RS issues and challenges post-COVID-19 faced by the Indian export-oriented apparel SC stakeholders and helps the policymakers like the government, councils, and industry associations to understand these issues and plan a course of action for making the industry competitive. In the delivery system, through a trustable agreement, creating a common information platform, and strong collaboration between suppliers, manufacturers, and buyers, a sustainable initiative for enhancing a resilient industry can be created.

Industry can benchmark sustainable practices required in the post-COVID-19 era, define strategic partnerships, provide training, and generate funds for facilitating a common information-sharing platform for upstream SC members. The AI-enabled platform supports every member in creating a resilient and sustainable SC hence, Export Councils can play a critical role among the regulators, buyers, and industry associations to promote concrete agreements, and secure a secured digital platform for stakeholders in the apparel industry. A strong IT system proposed can monitor and build security checks with an unbiased approach towards members of the SC for strong engagement with suppliers, manufacturers, brands, and customers for any unexpected events. Application and adoption of AI-enabled systems can support collaboration, communication, information sharing, security, demand and supply data, inventory management, augmented design prototype, IoT, and sustainability parameters understanding in the upstream and downstream. The adoption of advanced manufacturing Industry 4.0 AI-enabled for operational capabilities and sustainability reporting was addressed to reduce inefficiencies and meet the uncertainties like that caused by COVID-19. Hence, the final implementation model helps provide clarity on the research area and creates a future research base. This study has brought generic insights of significant value to operations and supply chain management of resilient and sustainability issues.

6. Conclusion and Future Research

The study develops a framework for identifying and applying powerful Industry 4.0 AI techniques to manage SC resilience and sustainability issues, building (Negri et. al, 2021) advances in research and practice on this interesting interface. The study is targeted in the apparel supply chain in emerging economies as they are still struggling to manage integrated aspects in their operations. SSM has been used to develop a conceptual framework for identifying issues encountered by the actors in the SC in the post-COVID-19 era. Later the study develops a final implementation model which acts as a solution to manage RS issues in the apparel SC. In the first phase. resilient and sustainable issues were identified with the through literature and semi-structured interviews and field visits and major issues identified are responsiveness and infrangible contracts, operational flexibility and adaptability, operational capabilities and efficiency, and collaborative and strategic partnerships requirement in the supply chain post COVID-19.

Later the research work identifies root causes for these issues among apparel SC actors that inhibit effective operation in the supply chain, which includes lack of collaboration, operational challenges, logistic infrastructure challenges,

and inadequate information-sharing platform in Indian context. Based on the identified root causes and the CATWOE analysis, the final root definition has been identified, used to frame the conceptual model using the broad parameters of delivery system, enabled system and criteria system. The delivery system is responsible for building RS apparel supply chain. Industry 4.0 AI-enabled system will support transparency and accountability in the implementation strategies for managing RS issues that can significantly improve demand forecasting, optimizing inventory and production, enhancing transparency, and managing risks effectively. Its role in promoting sustainability and ethical practices further strengthens the supply chain's adaptability and responsiveness to disruptions. As the export-oriented apparel industry is of economic importance to India, it needs attention from its stakeholders for a creating robust future especially the regulatory bodies and Apparel Export Promotion Council need to infuse Industry 4.0 AI-technology for forecasting, contracts, operation capabilities in the apparel supply chain to enhance exports contribution. In this work, the author has tried to present a holistic view of the sector post COVID-19 times. Thus, continued advancements in AI technology and its integration into the supply chain processes are expected to drive further innovation, efficiency, and sustainability in the apparel value chain.

This study too has limitations, like the culture, location, and sector-specific environment in which it operates. Even collecting data through meetings and interviews was difficult, as the information shared was based on individual perceptions and the sensitivity to sharing the confidential and partial attitudes of respondents. The study was mostly conducted in the northern part and was specific to the apparel sector, bringing out the various issues and challenges faced by stakeholders' post COVID-19. Further research can be done at specific levels, like SMEs, benchmarking the AI adoption best practices in the industry, and exploring the mitigating of the Industry 4.0 AI adoption issues and challenges, ranking the issues depending on their severity. Also, a further extended study can be conducted on the subsystems and comparison of technology with developed economies to gain insights into the impact on resilient and sustainable issues.

References

AEPC Report, AEPC Study on Impact on COVID-19 on Apparel Sector, https://aepcindia.com/system/files/ AEPC Covid Study, May 8, 2020, accessed on November 12, 2023

Ahi, P., & Searcy, C., A comparative literature analysis of definitions for green and sustainable supply chain management, *Journal of Cleaner Production*, vol. 52, pp. 329–341. 2013.

Ali, A., Mahfouz, A., & Arisha, A., Analysing supply chain resilience: Integrating the constructs in a concept mapping framework via a systematic literature review. Supply Chain Management, vol. 22, no. 1, pp. 16–39, 2017.

Anil, K., Rohit Kr. S. and Devnaad S., Supply chain resilience in developing countries: a bibliometric analysis and future research directions, *Benchmarking: An International Journal*, vol. 31, no. 7, pp. 2217-2238, 2024.

Baldwin, R. E., and Evenett, S. J., Global supply chains will not be the same in the post-COVID-19 world, COVID-19 and Trade Policy: Why Turning Inward Won't Work, Centre for Economic Policy Research, London, 2020.

Bag, S., Gupta, S., & Foropon, C., Examining the role of dynamic remanufacturing capability on supply chain resilience in circular economy. *Management Decision*, vol. 57, no. 4, pp. 863–885, 2019.

Belhadi, A., Kamble, S., Gunasekaran, A. and Mani, V., Analyzing the mediating role of organizational ambidexterity and digital business transformation on industry 4.0 capabilities and sustainable supply chain performance, *Supply Chain Management*, vol. 27, no. 6, pp. 696-711, 2022.

Calvo-Amodio, J., "Using principles as activity drivers in human activity systems", Systems Research and Behavioral Science, Vol. 36 No. 5, pp. 678-686. 2019

Checkland, P., & Poulter, J., Learning for action: A short definitive account of Soft Systems Methodology and its use for practitioners, teachers and students. Chichester, United Kingdom: Wiley. 2006.

Checkland, P., Soft Systems Methodology: A thirty-year retrospective. *Systems Research and Behavioural Science,* vol. 17, pp. 11–58. 2000

Christopher, M., & Peck, H., Building the resilient supply chain, *International Journal of Logistics Management*, vol. 15, no. 2, pp. 1–13, 2004.

Chowdhury, M.M.H. and Quaddus, M., Supply chain resilience: conceptualization and scale development using dynamic capability theory, *International Journal of Production Economics*, vol. 188, pp. 185-204, 2017.

Crane, A. and Matten, D., COVID-19 and the future of CSR research, *Journal of Management Studies*, vol. 58, no.1, pp.280-284, 2020.

Darvishmotevali, M., Levent, A., and Mehmet, A. K., The link between environmental uncertainty, organizational agility, and organizational creativity in the hotel industry, *International Journal of Hospitality Management,* Vol. 87, p. 102499, 2020.

Deloitte, Insights (2022) available at https://www2.deloitte.com/us/en/insights/industry/ manufacturing/realigning-global-supply-chain-management-networks.html, Accessed on Dec 15, 2022.

Dohale, V., Verma, P., Gunasekaran, A. and Ambilkar, P., COVID-19 and supply chain risk mitigation: a case study from India", *The International Journal of Logistics Management*, vol. 34, no. 2, pp. 417-442, 2023.

Dubey, R., Gunasekaran, A., Bryde, D.J., Dwivedi, Y.K. and Papadopoulos, T., Blockchain technology for enhancing swift-trust, collaboration and resilience within a humanitarian supply chain setting, *International Journal of Production Research*, Vol. 58, no. 11, pp. 3381-3398, 2020.

Fam, D., Palmer, J., Riedy, C. and Mitchell, C. (Eds), Transdisciplinary Research and Practice for Sustainability Outcomes, Routledge, New York. 2017.

Gereffi, G.,What does the COVID-19 pandemic teach us about global value chains? The case of medical supplies, *Journal of International Business Policy*, Vol. 3 No. 3, pp.287-301, 2020.

Gerwel Proches and Bodhanya, An Application of Soft Systems Methodology in the Sugar Industry, International Journal of Quality Methods, vol. 5, 2015

Ghobakhloo, M., Iranmanesh, M., Foroughi, B., Tseng, M. L., Nikbin, D., & Khanfar, A. A, A Industry 4.0 digital transformation and opportunities for supply chain resilience: a comprehensive review and a strategic roadmap, *Production Planning & Control*, pp. 1–31, 2023.

Giannakis, M., Spanaki, K. and Dubey, R., A cloud-based supply chain management system: effects on supply chain responsiveness, *Journal of Enterprise Information Management*, vol. 32, no. 4, pp. 585-607, 2019.

Golan, M.S., Jernegan, L.H. and Linkov, I.,Trends and applications of resilience analytics in supply chain modeling: systematic literature review in the context of the COVID-19 pandemic, *Environment Systems and Decisions*, vol.40, no.2, pp.222-243, 2020.

Golgeci, I., Yildiz, H.E. and Andersson, U.R., The rising tensions between efficiency and resilience in global value chains in the post-COVID-19 world", *Transnational Corporations*, Vol.27 No.2, pp.127-141, 2020.

Gouda, S.-K., & Saranga, H., Sustainable supply chains for supply chain sustainability: Impact of sustainability efforts on supply chain risk, *International Journal of Production Research*, vol. 56, no. 17, pp. 5820–5835, 2018

Gunasekaran, A., Subramanian, N. and Rahman, S., Supply chain resilience: role of complexities and strategies, *International Journal of Production Research*, Vol. 53 No. 22, pp. 6809-6819. 2015

Gupta R, and Shankar R., Managing food security using blockchain-enabled traceability system. Benchmarking: An International Journal, vol. ahead of print 2023.

Hemant, J., Rajesh, R. and Daultani, Y.,Causal modelling of the enablers of CPFR for building resilience in manufacturing supply chains, *RAIRO-Operations Research*, vol. *56, no.* 4, pp.2139-2158, 2022.

Handfield, R.B., Graham, G. and Burns, L., Corona virus, tariffs, trade wars and supply chain evolutionary design, *International Journal of Operations & Production Management*, vol. 40, no. 10, pp.1649-1660. 2020.

Ishida, S., Perspectives on supply chain management in a pandemic and the post-COVID-19 era, *IEEE Engineering Management Review,* Vol. 48 No. 3, pp. 146-152. 2020.

Islam, M. S., Hoque, I., Rahman, S. M., & Salam, M. A., Evaluating supply chain resilience using supply chain management competencies in the garment industry: a post COVID analysis, *Journal of Industrial and Production Engineering*, vol,*40, no.* 5, pp. 323–342, 2023.

Ivanov, D., Supply Chain Viability and the COVID-19 pandemic: a conceptual and formal generalization of four major adaptation strategies, *International Journal of Production Research,* Vol. 59 No. 12, pp. 3535-3552. 2021.

Ivanov, D. and Dolgui, A., Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak", *International Journal of Production Research,* Vol. 58 No. 10, pp. 2904-2915, 2020.

Ivanov, D., Sokolov, B., and Dolgui, A., The Ripple effect in supply chains: trade-off 'efficiency-flexibility-resilience' in disruption management*, International Journal of Production Research*, Vol. 52 No. 7, pp. 2154-2172, 2014

Jabbarzadeh, A., Fahimnia, B., Sheu, J. B. and Moghadam, H. S., Designing a supply chain resilient to major disruptions and supply/demand interruptions, *Transportation Research Part B: Methodological,* Vol. 94, pp. 121-149. 2016.

Jain, V., Kumar, S., Soni, U., & Chandra, C., Supply chain resilience: Model development and empirical analysis, *International Journal of Production Research*, vol. 55, no. 22, pp. 6779–6800, 2017.

Kamalahmadi, M. and Parast, M.M., A review of the literature on the principles of enterprise and supply chain resilience: major findings and directions for future research, *International Journal of Production Economics*, Vol. 171, pp. 116-133, 2016

Khurana, K., The Indian fashion and textile sector in and post COVID-19 times., *Fashion Textiles,* vol. 9, p. 15, 2022

Kadambi, B., "IT-Enabled supply chain management – a preliminary study of few manufacturing companies in India", available at: www.xlri.ac.in/cltm/LogistiX-2-2000.html, 2000

Kumar V, Vrat P, and Shankar R, Factors influencing the implementation of industry 4.0 for sustainability in manufacturing. Global J Flex Syst Manage 23, no.4, pp.453–478, 2022.

Kumar, V., Shankar, R., and Vrat, P., Managing Implementation Issues in Industry 4.0: A soft Systems Methodology-based Approach, 2024.

Le, P.B., Determinants of frugal innovation for firms in emerging markets: the roles of leadership, knowledge sharing and collaborative culture, *International Journal of Emerging Markets.* 2021.

Luthra, S., Garg, D. and Haleem, A., Identifying and ranking of strategies to implement green supply chain management in Indian manufacturing industry using analytical hierarchy process, *Journal of Industrial Engineering and Management*, Vol. 6 No.4, pp. 930-962, 2013

Mandal, A., Roychowdhury, S. and Biswas, J., Performance analysis of major ports in India: a quantitative approach, *International Journal of Business Performance Management*, vol. 17, no. 3, pp. 345-364, 2016.

Majumdar, A., Shaw, M. and Sinha, S.K., COVID-19 debunks the myth of socially sustainable supply chain: a case of the clothing industry in South Asian countries, *Sustainable Production and Consumption*, Vol. 24, pp. 150-155, 2020.

Majumdar, A., and Sinha, K.S., Analyzing the barriers of green textile supply chain management in South East Asia using Interpretive structural modelling, *Sustainable Production and Consumption,* Vol. 17, pp. 176–187, 2019

Marinagi, C., Reklitis, P., Trivellas, P. and Sakas, D., The impact of industry 4.0 technologies on key performance indicators for a resilient supply chain 4.0, *Sustainability,* vol. 15, no. 6, p. 5185, 2023.

McKinsey Report 2020 "a-devilish-duality-how-ceos-can-square-resilience-with-net-zero-promises-final. Accessed on September 14, 2024.

Munim, Z. H., Mohammadi, M., Shakil, M. H. and Ali, S. M., Assessing measures implemented by export-oriented RMG firms in an emerging economy during COVID-19, *Computers and Industrial Engineering*, Vol. 165, 2022.

Negri, M., Cagno, E., Colicchia, C. and Sarkis, J., Integrating sustainability and resilience in the supply chain: A systematic literature review and a research agenda, *Business Strategy and the environment*, vol. *30, no.* 7, pp. 2858-2886, 2021.

Ngai E. W. T., Peng, S., Alexander, P and Moon, K. L. K., Decision support and intelligent systems in the textile and apparel supply chain: An academic review of research articles, *Expert Systems with Applications*, vol. 41, pp. 81–91, 2014

Ngai E. W. T., Chester K.M. To, Vincent S.M. Ching, L.K. Chan , Lee, M. C. M., Choi, Y. S., Chai, P.Y.F., Development of the conceptual model of energy and utility management in textile processing: A soft systems approach Intern. *Journal of Production Economy*, vol. 135, no. 2 pp. 607–617, 2012.

Nguyen, M.A.T., Lei, H., Vu, K.D. and Le, P.B., The role of cognitive proximity on supply chain collaboration for radical and incremental innovation: a study of a transition economy, *Journal of Business and Industrial Marketing*, Vol. 34 No. 3, pp. 591-604, 2019.

Nayal, K., Raut, R., Priyadarshinee, P., Narkhede, B.E., Kazancoglu, Y. and Narwane, V., Exploring the role of artificial intelligence in managing agricultural supply chain risk to counter the impacts of the COVID-19 pandemic", *The International Journal of Logistics Management*, Vol. 33 No. 3, pp. 744-772, 2022

Nurani T W Wahyuningrum P I Wisudo S H Gigentika S and Arhatin R E, 2018 Model designs of Indonesian tuna fishery management in the Indian Ocean (FMA 573) using soft system methodology approach *Egypt. J. Aquat. Res.* 44, 2 pp. 139–144.2018.

Nurhasanah, N., Machfud, Mangunwidjaja, and M Romli, International Operations and Production Conference Series: Materials Science and Engineering, 847,2020.

Paucar-Caceres A, Cavalcanti-Bandos MF, Quispe-Prieto SC, Huerta-Tantalean LN, Werner-Masters K., Using soft systems methodology to align community projects with sustainability development in higher education stakeholders' networks in a Brazilian university. *Sys Res Behavioural Science* , vol.39, no. 4, pp. 750–764, 2022

Patidar, A., Sharma, M., Agrawal, R. and Sangwan, K.S., Supply chain resilience and its key performance indicators: an evaluation under Industry 4.0 and sustainability perspective", *Management of Environmental Quality: An International Journal,* Vol. 34 No. 4, pp. 962-980, 2022.

Pettit, T., Fiksel, J. and Croxton, K., Ensuring supply chain resilience: development of a conceptual framework, *Journal of Business Logistics*, Vol. 31 No. 1, pp. 1-21. 2010

Pettit, T., Croxton, K. and Fiksel, J., The evolution of resilience in supply chain management: a retrospective on ensuring supply chain resilience, *Journal of Business Logistics,* Vol. 40 No. 1, pp. 56-65.2019

Rahman, T., Taghikhah, F., Paul, S. K., Shukla, N., and Agarwal, R., An agent-based model for supply chain recovery in the wake of the COVID-19 pandemic, *Computer and Industrial Engineering*, Vol. 158(c), p. 107401, 2021.

Rajesh, R., On sustainability, resilience, and the sustainable resilient supply networks. *Sustainable Production and Consumption,* 15, 74–88., 2018.

Reid, J. I., Gray, D. I., Kelly, T. C., & Kemp, E. A. (1999). An application of SSM in the on-farm labour situation in the New Zealand dairy industry. *Systems Research and Behavioural Science,* vol 16, pp. 341–350, 1999.

Salman, S., Ahmed, T., Taqi, H.M.M., Frederico, G.F., Dip, A.S. and Ali, S.M., An integrated approach to explore the barriers to lean manufacturing in the context of the COVID-19 pandemic: implications for sustainability, *International Journal of Industrial Engineering and Operations Management*, Vol. 6 No. 2, pp. 165-184. 2024.

Scholten, K., Sharkey Scott, P. and Fynes, B., Building routines for non-routine events: supply chain resilience learning mechanisms and their antecedents, *Supply Chain Management: An International Journal,* Vol. 24 No. 3, pp. 430-442, 2019

Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L., Blockchain technology and its relationships to sustainable supply chain management, *International Journal of Production Research*, Vol. 57 No. 7, pp. 2117-2135, 2019.

Sauer, P.C., Silva, M.E. and Schleper, M.C., Supply chains' sustainability trajectories and resilience: a learning perspective in turbulent environment*", International Journal of Operations and Production Management*, Vol. 42 No. 8, pp. 1109-1145, 2021

Shankar, R., Acharia, S. and Baveja., Soft-system knowledge management framework for new product development, *Journal of Knowledge Management,* Vol. 13 No. 1, pp. 135-153, 2009.

Shin, N., & Park, S., Evidence-based resilience management for supply chain sustainability: An interpretive structural modelling approach. *Sustainability*, vol. 11, no. 2, 484, 2019.

Shinghry, H. B. and Rahman, A., Enhancing supply chain performance through collaborative planning, forecasting, and replenishment, *Journal of Business Process Management*, Vol. 24 No. 4, pp. 965–984,2018.

Sgourou, E., Katsakiori, P., Papaioannou, I., Goutsos, S., and Adamides, E., Using Soft Systems Methodology as a Systemic Approach to Safety Performance Evaluation, *Procedia Engineering*, Vol 45, pp. 185-193, 2012.

Tortorella, G., Fogliatto, F.S., Gao, S. and Chan, T.K., Contributions of Industry 4.0 to supply chain resilience, *The International Journal of Logistics Management,* vol. 33, no. 2, pp. 547-566, 2020.

United Nations, "The Sustainable Development Goals Report 2020", https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf, (accessed on 15.06.2022).

Van den Adel, M. J., de Vries, T. A. and Van Donk, D. P., Improving cross-functional teams' effectiveness during supply chain disruptions: the importance of information scouting and internal integration, *Supply Chain Management,* Vol. (ahead-of-print) No.(ahead-of-print), 2022

Wang W, Liu W, and Mingers J., A systemic method for organisational stakeholder identification and analysis using Soft Systems Methodology (SSM). European Journal of Operations Research, vol. 246, no. 2, pp. 562–574, 2015

WHO Report 2020 . WHO Director-General's opening remarks at the media briefing on COVID-19 - 11 March 2020 https://www.who.int/dg/speeches/detail/whodirector-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020, accessed on June 10, 2022.

Zahiri, B., Zhuang, J., & Mohammadi, M., Toward an integrated sustainable-resilient supply chain: A pharmaceutical case study. *Transportation Research Part E: Logistics and Transportation Review*, vol. 103, pp. 109–142, 2017.

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APPENDIX-A(Table 4)

Table 4. Root causes of the issues

Root Causes	Issues
Lack of Collaboration	*Supplier-Manufacturer* - Coordination issue - Financial dependency - Management seriousness on sustainable practices - Lack trust and information sharing - Lack technical knowledge knowhow *Manufacturer- Buyer* - Lack information sharing - Lack top management initiative - Product prototype design and development issues - Lack understanding of brands sustainable reporting - Robust solutions for traceability not available - Predication and forecasting difficulties *Industry Association- Manufacturer* - Common platform for easy access of potential market data not available - Data on global sustainable product requirement not shared - Lack data collection of various countries sustainability policies and regulations - Insufficient facilitation for sharing of common services and resources *Manufacturer- Logistic provider* - Higher transportation and freight charges - Delay in the shipment - Real-time information not available *Regulator – Manufacturer*

	- Low initiative for foreign trade collaboration and partnerships for trade - No strategic partnership for internal and external market - Lack regular interactions for awareness of foreign trade policies - Non-availability of IT platform one common window *Buyer – Customer* - *Awareness of product Life-cycle assessment* - *Value for sustainable products*
Operational Incapabilities	*Supplier-Manufacturer* - Unskilled manpower - Lack of flexible production facilities and advance manufacturing technologies - Financial limitations - Worker social security non-compliance issues - Labour problems *Manufacturer- Buyer* - Delay in design approvals and digital design not accepted - Pressure to subcontract the work due to time pressure - Incorrect capacity information sharing - Varied social and environmental compliance parameters - Higher lead time - Product traceability issues *Manufacturer- Industry associations* - Lack active Interaction - International standards on sustainability and environmental norms not available - Use of common resource not encouraged for enhancing productivity *Manufacturer- Logistic Providers* - Unreliable and untrained staff - Status of freight not available - Containers not available - Clearance issues - Higher rates
Logistic infrastructure challenges	*Supplier-Manufacturer* - Untrained staff - Financial - Unreliable third-party transporter - Import restrictions *Manufacturer- Buyer* - Lack of capacity - High air freight used for delivery - Contracted worker and social sustainability issues - Export documentation delayed - Unpredictability of sea shipment - Rejection of shipment *Manufacturer- Logistic Provider* - Containers availability issues - Vehicle quality issues - Port clearance - Traceability of the consignment *Regulators – Logistic providers* - Insufficient IT platform policies - Policies for easy of the road taxes and transportation

	- Internet access and digital technology availability to support competitiveness
Inadequate information-sharing Platform	*Supplier-Manufacturer* - Secured and common IT platform not available - Suppliers' evaluation system not practiced - Security concerns - Financial constraints to adopt digital technology mechanism *Manufacturer- Buyer* - Issues in the traceability - Lack trust - Delay in payment and penalties - Product prototype development and sharing issues - Real-time information of shipment - Predication and forecasting difficulties due to inadequate data sharing - Product life-cycle Assessment criteria *Manufacturer- Industry Associations* - Lack potential market information - Standard Policy for forecasting and market trends - Trained manpower through training institutes not available - Manufacturing facilities collaboration *Regulator – Industry Associations* - Lack information shared on foreign sustainable polices and regulations *Buyer – Logistic provider* - Real-time information not available - Vehicle tracking issue - Robust solutions for timely delivery not available - Privacy and security issues *Buyer- Regulators* - Lack initiative for uniform compliance of sustainable practices for major buyers and countries *Buyer -Customer* - Lack trust on the environmental and social sustainable information - Ethical sourcing information