Sustainable and Resilience Improvement Through the Design for Circular Digital Supply Chain

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Abstract. Resilient and sustainable supply chain management (SCM) practices have been established in recent decades to reduce the likelihood and consequences of disruptions and the negative environmental effects along the supply chain. To deal with such issues, it's important to be able to quantify the effectiveness of all supply chain processes in a circular economy model while taking technological revolution into account. Furthermore, Design for X (DFX) approaches show significant potential for improving product and service functionality from a variety of perspectives X. In this respect, the aim of this paper is first to propose a circular digital SCOR model that depicts the impact of digital technology on various circular SCOR processes. Second, using DFX techniques, a conceptual model, called Design for circular digital Supply chain (DFCDSC), has been proposed that includes the key design factors for the development and implementation of the circular digital supply chains. Since it highlights the main lines of research in the area, the proposed framework will provide crucial managerial perspectives for practitioners and managers.

Keywords: Resilience, Sustainability, Supply Chain Management, Design for X, Circular Economy, Digital technologies.

1 Introduction

In the current global scenario and increasingly complex, digital world, supply chains (SC) are faced various events that interrupt SC operational processes and successful performance. Furthermore, consumers, regulators, and other stakeholders around the world are pushing corporations to conduct their activities responsibly to boost their economic, social and environmental efficiency [1]. Thus, organizations were forced to adjust their activities and take a constructive position in creating safer and more resilient systems to meet the needs of all stakeholders while improving sustainability outcomes [2]. In this context, Circular economy (CE) and emerging technologies have emerged as key elements of the sustainability and resilience response to assist organizations in being more successful [3].

Through the achievement of collaboration, transparency, resiliency, responsiveness, and flexibility across all SC processes, DSC can have clear sight in real time [4]. Besides, organizations that consider CE gain from material saving, reduced manufacturing and supply costs, improved customer loyalty, and the ability to keep products and parts in use for a longer time [3]. Moreover, when SC is influenced by changes in the operational and environmental conditions, resilience capabilities allow adaptation and recovery[4]. Furthermore, a successful transition to sustainability dependent on a variety of social, economic, legal, cultural, and political factors, and it necessitates fundamental changes, not only at the company level but also across the product and service activities [5]. Methods and tools to enable the systematic integration of all products and services concerns from a digital and circular and perspective, however, are still being developed. From a particular X viewpoint, the Design for X (DFX) approach is used to increase the quality of the product and SC processes [6, 7].

Many authors explored and explained how to perceive the CE transition through the use of DFX approaches [3, 8]. Other researchers have created new DFX methods as part of the introduction of Industry 4.0 by DFX techniques [9]. Therefore, no paper dealing specifically with the incorporation of the CE and digitalization to achieve sustainable and resilient concerns in the SC based on the DFX perspective can be found among all the advances made and research contributions. In this respect, the aim of this paper is first to develop a circular-digital SCOR model which serves as a reference model for the enhancement of SCs. Then, by considering the prominent DFX techniques needed in each circular-digital SCOR model, a series of design factors have been enumerated to integrate circular and digital concerns in SC to reach resiliency and sustainability enhancement. The conceptual framework, design for circular digital supply chain (DFCDSC), will provide crucial and managerial implications for both practionners and managers to develop dynamics capabilities theory.

This paper is structured as follows; Sect. 2 presents an analysis of the literature review. Section 3 elaborates the proposed circular digital SCOR model for the integration of circular and digital impacts on the SC. Section 4 proposes the theoretical elements of our integrated model DFCDSC. The key design factors needed to implement DFCDSC fir resilient & sustainable purpose is established. Section 5 presents implications for both practitioners and researchers. The conclusions and future works are drawn in the final section.

2 Literature review

Considering the high competition atmosphere and technological transition (Industry 4.0), organizations have begun to concentrate on sustainable practices to resolve environmental, social, and economic issues, forming an agenda that aims to promote resilience, digitalization, and circularity along the SC.

2.1 Circular Supply Chain

The CE is characterized as an economic model in which resources are used for as long as possible while extracting maximum value. By reducing (or delaying) unintended negative environmental impacts, the principles of CE broaden the boundary of green, resilience and sustainable SCM [3, 10]. In this regard, as the world moves toward a CE, SCs players are paying more attention to their environmental effects, and opportunities to generate value through minimizing, preserving, and recovering natural resources. “Open-loop SC”, “circular SC”, and “closed-loop SC”, are all terms used to describe SCs in a CE [3, 8]. More clearly, CSCM includes a vision of a zero-waste economy, restorative and regenerative cycles planned using circular thinking. Motivated by all these benefits, several researchers have contributed significantly to the literature on the CE.

Several authors have suggested a complete rethinking of the way products, processes and SC are designed by using DFX Techniques[3, 11]. Further ones have studied drivers, barriers and enable for the integration of CE in SCM [12, 13]. Researchers have also focused on elaborating frameworks for the CSCM [1, 12, 14] with the integration of green, reverse logistics, industrial ecology with CE concerns. Other ones have included the benefits of using Industry 4.0 technologies such as Additive manufacturing with circular SC [15, 16].

2.2 Digital Supply Chain

Technological and computing advancements have led to a rapidly evolving environment in recent decades [17]. Companies need a digital supply chain (DSC) based on sustainability, visibility, efficiency and flexibility to help them solve the challenges of volatility, resiliency, uncertainty, and transparency [18]. According to [18], DSC can be defined as “an intelligent best-fit technological system that is based on the capability of massive data disposal and excellent cooperation and communication for digital hardware, software, and networks to support and synchronize interaction between organizations by making services more valuable, accessible and affordable with consistent, agile and effective outcomes”. This implies a collection of advanced technologies that companies must integrate with human capital to transform their SCs from a traditional to instrumented, integrated and intelligent one [19]. Therefore, DSC is about how SCs are handled; how both digital and physical flows help to achieve visibility and quality enhancement as well as real-time feedback at all levels[20].

DSC implementation has gotten high attention from many practionners and academicians. Among the contributions to this research field, few research papers have attempted to implement DSC [1, 18]. Several authors have used systematic reviews to concentrate on advanced technologies effect on SCs, such as “Big Data”, “Internet of Things”, “Cyber Security” and “Augmented Reality”. Other ones have contextualized IT in a SC 4.0 [21, 22]. Further, established a structure for understanding DSC based on an overview of key advantages and limitations [18, 19].

3 Circular-Digital SCOR model

The SCOR model is a known structure that divides SC processes into six sub-processes (“plan, source, make, deliver, return, and enable”) that serve as the foundation to describe any SC [23]. To achieve sustainability, it is important to assess the actual efficiency of all SC processes in a circular context. To do so, two processes have been added to the standard SCOR model: (1) Use that represents the endconsumption users of the products as well as maintenance and repair activities to the extent the product lifespan and (2) Recover that represents the remanufacture, reuse, recycle, repair and redesign activities. Furthermore, since the conventional SC is made up of a series of siloed steps, incorporating digital technology may be able to break down these barriers and turn them into a seamless system [18, 19]. Fig.1 represents the circular and digital SCOR (CDSCOR) model that depicts the effect of digital technologies on the various circular proposed processes.

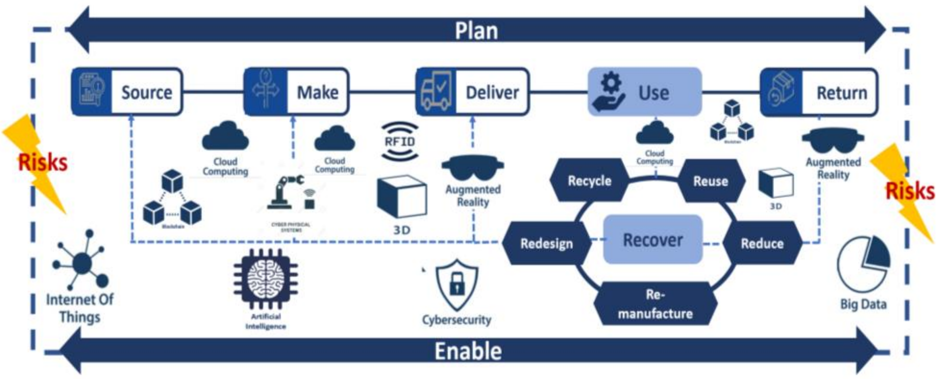

Fig. 1. Proposed Circular-Digital SCOR model (CDSCOR)

For the Make, Deliver, and Return processes, 3D printing aids in the development of product prototypes for evaluation, as well as mass customization [24]. Cloud Computing encourages collaboration among SC participants, improves connectivity, and adaptability in the Use, Make, and Source processes [25]. In both Deliver and Return processes, AR increases their efficiency and visibility [26]. The CPS, which is primarily used in the Make process, through the use of interconnected computers, physical processes and networks assess agility by contributing to production and inventory optimization [27]. Besides, RFID allows real-time detection and tracking, which helps to improve data quality [20]. Whereas, Blockchain technology enables the real-time enhancement and monitoring of products and actors, especially for Use and Source processes [28]. In contrast, other techniques such as BD, Cybersecurity, IoT and AI have positive impacts on the entire SC processes. BD gives better forecast, increase SC visibility and strong relationships[20]. IoT help increasing warehouse operations productivity, and unnecessary procedures. In addition to all of these advantages, risk management and control in a DSC would concentrate primarily on cybersecurity, as it is required to identify security incidents, enforce the appropriate safeguarding tools, react to attacks in real-time[19]. Furthermore, AI improves the efficiency of SC drivers by developing a great understanding of their interactions [29]. As a result, by considering CDSCOR model, we connect SC actors to create reliability, transparency, resiliency, and effectiveness in the end-to-end sustainable value chain by including the Use and Recover processes and incorporating Industry 4.0 technologies.

4 Design for Circular Digital Supply Chain

Given the high level of concurrence, SC must meet new digital and circular features, as well as ensure the integration of resilience and sustainable practices with multiple conventional functionalities. Furthermore, mastering the management of an organization's intellectual resources is critical. As a result, successful SCs have a strong vision and use structures and roadmaps to drive them forward. In this regard, the original structure depicted in Figure 2 presents a roadmap for better understanding the problem of SC sustainability and resilience when taking into account an integrated vision that involves circularity, industry 4.0, and DFX techniques capabilities. More clearly, the framework, called Design for Circular Digital Supply Chain (DFCDSC), defines a set of over 300 design factors that must be considered for each of the proposed CDSCOR processes to achieve sustainability and resilience efficiency outcomes. Therefore, it's important to note that the design factors within each process come from a variety of sources, including applications, guidelines, papers, books, and real design projects and the main DFX techniques used in each process are based on the categorization of [5]. In the following, a discussion of each process is presented.

- The **Plan** process purpose is to define SC needs and align them against available assets and resources. Environmental limits, such as the environment's assimilative potential and resource extraction relative to yield, are primarily considered in a CE context. Using Industry 4.0 technologies capabilities, we obtain a synchronized & digital planning with a real-time inventory & disruption prediction.
- The **Source** process aims to organize product deliveries, obtain and validate the product, pass the product, and approve payment to the supplier. Sourcing is linked to all resource principles in the CE model, including sustainable, exhaustible, and renewable resources. Besides, to achieve resilience, back-up suppliers should be incorporated, component replacement and supplier communication portals should be used. Using Industry 4.0 technologies capabilities, we obtain intelligent supply and predictive analysis sourcing.
- The **Make** process aims to organize manufacturing activities, issue materials, manufacture and test, deliver products, and stage products while taking into account waste disposal and packaging limitations. Make covers tasks such as maintenance, recovery, recycling, and material transformation from a circular perspective. Furthermore, flexible manufacturing lines and the application of postponement concepts are regarded as critical drivers of demand resilience and responsiveness. Using Industry 4.0 technologies capabilities, we establish a smart factory and a proactive risk sensing to adjust manufacturing capabilities.
- The **Deliver** process describes the tasks associated with building loads, routing packages, selecting carriers, receiving products, picking, packing, documenting, shipping, installing the product, and fulfilling customer orders. Deliver can also coordinate the supply of replacement parts for repair during usage of the product in a circular context to prolong the product's lifespan. Besides, omnichannel delivery, decentralized logistics, disturbance monitoring, and real-time transportation control

are some of the other ways to easily and efficiently use resilience assets. Using Industry 4,0, technologies capabilities we obtain dynamic fulfillment with full inventory transparency and dynamic/predictive routing.

- The **Use** process includes the end-usage user's or use of the product, as well as repair and maintenance to extend the product's lifespan. In a CE, end-users need to return their goods at the end of their useful lives, as these goods are 'after recovery' inputs for the manufacturing process. Besides, using Industry 4.0, we obtain a connected & responsiveness customer.
- The **Return** process to return material from the end-user to the SC return material. Moreover, resource-related practices which specifically include the return of a faulty or unnecessary product can be linked to the CE's consumer product construct. Recycled products, closed-loop SC tools and constructive procurement dependent plans are all examples of ways to use resilience assets for creating value in the return process. Using Industry 4.0 capabilities, we obtain End to end transparency for customers.
- The **Recovery** process includes the processes of Remanufacturing, recycling, reusing, reducing and redesigning. As a fully circular operation, it takes into account all aspects of assembly, disassembly, remanufacture, and recycling policies, as well as CO2 emissions, hazardous effects, and essential materials. Using the Industry 4.0 technologies capabilities, we obtain intelligent traceability, collaborative value capture and zero landfills.
- The **Enable** process refers to the SCM process, which involves business regulations, facility efficiency, data resources, contracts, enforcement, and risk management, among other things. In a circular perspective, the enablers that were not evident in a linear business model are taken into account. Materials would be sourced not only from manufacturers but also from end-users who are disposing of their obsolete goods. Furthermore, DSC twins and Industry 4.0 technologies enable several vital resilience capabilities, including coordination, visibility and collaboration.

In a summary, by considering the proposed DFCDSC, a specific set of performance objectives such as agility, flexibility, visibility, transparency, security, proactivity, adaptability can be reached. In addition to that, by considering both internal (Errors made by humans, computer malfunctions, and product consistency) and external risks (natural disasters, pandemics, exchange rates, legislations) resiliency can be achieved. There are also several sustainability advantages to be gained. From an economic standpoint, expenses are decreased while sales and profitability are improved. From an ecological standpoint, there is a reduction in carbon footprint, resource depletion, pollution and toxicity. Finally, on a social level, wages, workplace safety and health, social justice, life expectancy, and education are all enhanced, whereas excessive working hours, severe poverty, and child labor are reduced. In this respect, the proposed system can give insights into the consideration of circular, digital, and DFX techniques to have a SC that is both sustainable and resilient.

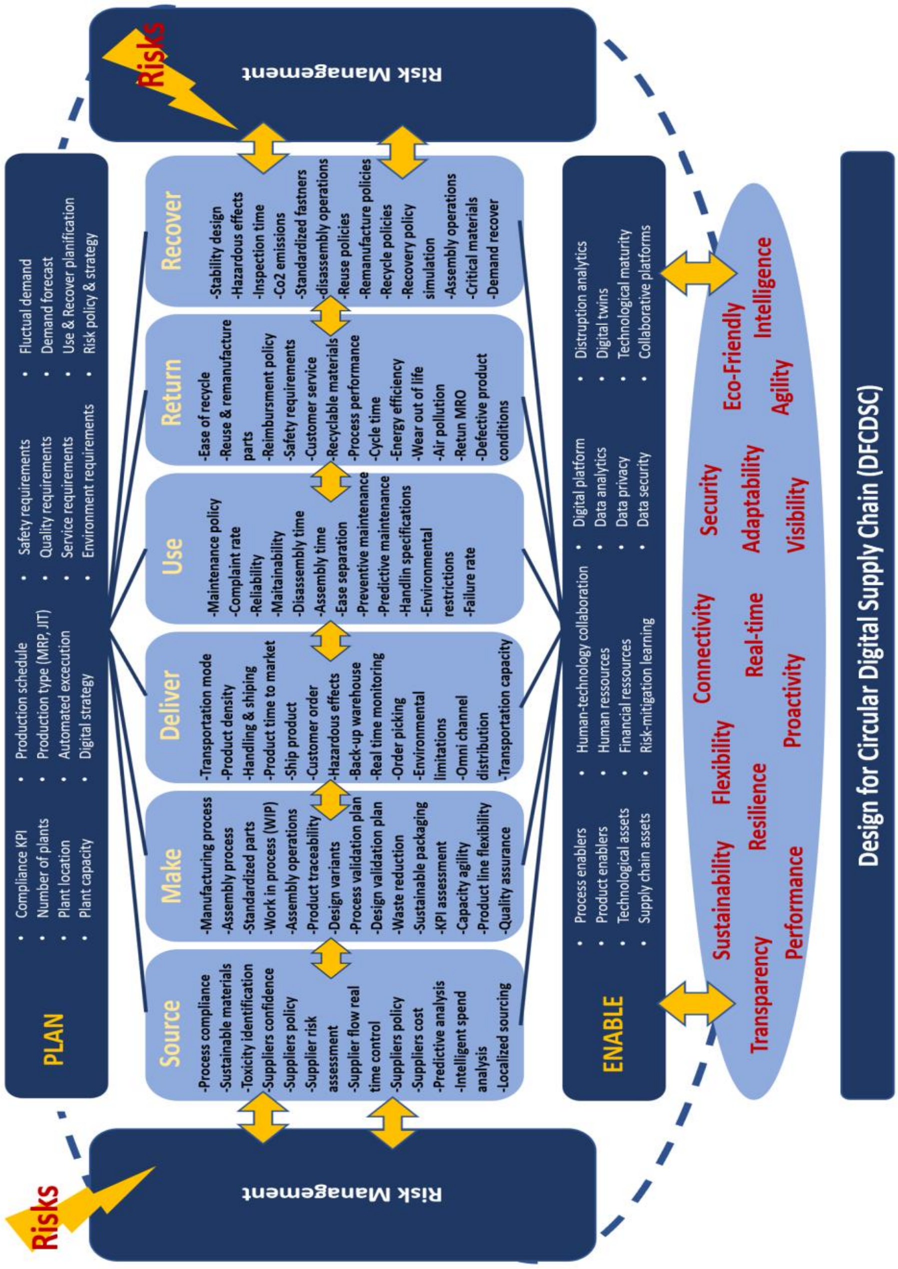

Fig. 2. Design for Circular Digital Supply Chain (DFCDS)

5 Managerial and practionners implications

From a managerial and practical perspective, the proposed DFCDSC framework will provide important insights for practionners, decision-makers, and anyone interested in acquiring a more in-depth understanding when incorporating DFX strategies, circularity, and digitalization in SC. More clearly, from a practionners point of view, this paper can help them to facilitate the adaptation to a circular-digital SC while using DFX techniques. Second, in light of significant influential papers in digital [18, 19] and circular SC [3], our paper contributes significantly by proposing a SCOR categorization model that incorporates both digitalization and circularity into the SC processes. Besides, a conceptual model for the development and implementation of CDSC has been suggested, which includes the main design factors needed to enhance sustainability and resiliency. This is as far as we know, the first attempt to establish the DFCSSC definition. It is then considered as a significant contribution to theory as it adds a solid structure that combines cutting-edge technologies with DFX techniques to gain a deeper understanding of digital complexities in a CSC. From the Managers point of view, the proposed framework assists them in ensuring that CSC operations are more environmentally aware and offers a roadmap in terms of economic, financial, social, logistical, organizational and operational activities to successfully implement CSC models. Furthermore, the proposed structure emphasizes that in the digital age, managers are continuously forced to strengthen their understanding of cutting-edge technology to promote the adoption, deployment, and dissemination of the key technologies that help SCM sustainability and resiliency. In summary, we conclude that the proposed structure, as well as the CDSCOR model, will serve as a useful guide for DSC project managers, consultants, and practitioners. Furthermore, the DSCC structure can be enhanced in terms of SC participant engagement and appropriate to the needs and skills of a particular organization.

6 Conclusion and future works

The current competitive environment requires companies to be innovative in their production systems and to rethink the current use of resources and waste management by integrating, CE, digital technologies and DFX techniques into their SCs. However, to resolve all of these problems at once, much of the study has concentrated on the technical side. This means that products should be designed not only with an emphasis on how SC concepts enable products to adapt into a CE or digitalization framework but also with a focus on how products adapt to people's desires, needs and behavioral trends. To achieve sustainability and resiliency, we need strategies to help in the implementation of both digital and circular supply chain architecture, according to this viewpoint. To do so, first, we have proposed a new categorization of the SCOR model that incorporates circular and depicts the impact of emerging technology on each process. We've added the recovery and use processes, as well as the effect of various technologies on SC efficiency, such as BD, Cybersecurity, IoT, and AR. Second, we suggested a set of design factors to DFCDSC to boost resilience and sustainability issues while taking into account an integrated view of circular, digital, and DFX techniques in SC. As mentioned in section 5, this framework offers different insights for practitioners and managers.Nonetheless, there are some drawbacks to this article. To evaluate the applicability of these findings, further research is necessary. More precisely, there is a need to delve deeper into not only the direct connection between CSC processes while integrating circular and digital concerns, but to test the design factors in different scenarios. The ability to fully map the interrelationships between various design factors and their impact on the efficiency of the CDSC will be crucial in making realistic suggestions for maximizing return on investment. We propose also to regroup the design factors into homogenous modules to facilitate the implementation of this framework by using classification or clustering algorithms.

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