13. Supply Chain 4.0 and the Transition towards a Circular Economy

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1.0 INTRODUCTION

Significant overconsumption and overproduction, which both contribute to global warming by increasing atmospheric pollution and greenhouse gas emissions (GHG), as well as generating increased volumes of waste in landfills, have led to growing demand for natural raw material resources and caused heightened concerns about environmental sustainability (OECD, 2019). On 1 January 2016, the United Nations introduced 17 sustainable development goals (SDGs) to address these and other major issues (United Nations, 2022). Goal number 12 on responsible production and consumption highlights the importance of shifting from an end-of-life approach to a more restorative and regenerative system. Exploring and implementing circular economy (CE) principles has been identified as a potential approach for achieving this shift in production and consumption behaviour (Ellen MacArthur Foundation, 2013). The CE is an economic development approach that aims to eliminate waste and environmental degradation through the production of reusable or recyclable products and services. Important aspects of the CE include product development, reverse logistics, maintenance, repair, reuse, remanufacturing, refurbishing and recycling (Franconi et al., 2022). These strategies are sometimes clustered together and defined as attempts to slow, narrow and close the material and energy loops (Bocken et al., 2016, Geissdoerfer et al., 2017). The implementation of such strategies requires fundamental changes to supply chain (SC) and business structures (Stahel, 2010). Research examining manufacturing and supply chain management (SCM) shows that CE strategies are crucial for reaching efficiency and sustainability targets while minimizing environmental impact (Fahimnia et al., 2017; Govindan and Soleimani, 2017; Batista et al., 2018; Mishra et al., 2018; Fung et al., 2020). Consequently, there has been increasing interest in identifying how SC principles can be integrated with those of the CE, which has led to coining of the term circular supply chain (CSC) to describe the new approach to SCM (Angelis, et al., 2018; Batista et al., 2018; Farooque et al., 2019).

The CSC is a type of SC in which products/materials are continuously reused. Various scholars assert that Industry 4.0 will result in development of more effective CSCs since improved data and analytics are expected to enable businesses to track and manage their resources in an effective manner and optimize the movement of goods and resources (Dev et al., 2020, Kumar et al., 2021, Taddei et al., 2022). Industry 4.0, also known as the Fourth

Industrial Revolution, is the current trend of increased automation and data exchange in manufacturing production. Industry 4.0 includes a number of new technologies, such as the internet of things (IoT), big data, cloud computing (CC), digital twins, artificial intelligence (AI), and additive manufacturing, which are assisting various industries to improve their performance and productivity (Issa et al., 2018).

Data provides the foundation upon which all business decisions and actions are based, and the right data, collected and analysed correctly and accurately, can help organizations make informed decisions about where to focus their efforts, how to allocate resources and what strategies to implement (Lopes de Sousa Jabbour et al., 2018). However, the complexity of data collected in CSCs using multiple technologies leads to challenges in interpreting and translating the data into useful information to enable a truly circular economy. Data must be converted into information, knowledge and wisdom in order to be able to enhance the performance and efficiency of a SC at both the strategic and operational levels (Kristoffersen et al., 2020). Additionally, Industry 4.0 technologies are disruptive, and companies thus need to rethink and redesign their SCs as well as business models for efficient transformation to a circular model. This chapter seeks to answer the following research questions:

RQ1: How do digitally enabled technologies impact the services required for CE transitioning at different stages of a supply chain?
RQ2: How can industries utilize Industry 4.0 technologies to create value from data while enabling a circular supply chain?

To answer the research questions, this chapter utilizes an integrative literature review in order to understand the key concepts and relationships between the CE, Industry 4.0 and SCM ([illegible]raco et al., 20[illegible]). To gain a comprehensive understanding of the topic, the authors first performed a narrative review of academic and grey literature (Paez, 2017). Once the fundamental concepts and links were established, two case studies were analysed to investigate further how these concepts interact in a real-world situation. These cases showcase two organizations that have presented proposals for incorporating CE and Industry 4.0 features into their SCs. The cases were built on data collected through internet-based research.

The rest of this chapter is organized as follows. First the chapter explores the role of data within CSCs and how new actors can aggregate data to improve the circular value creation within the ecosystems/SCs. Next, the authors discuss how data can be processed and manipulated by Industry 4.0 technologies to create circular value and develop innovative business models. Two case examples are then introduced to showcase the role of Industry 4.0 in enhancing and improving business offerings. The final section of the chapter includes discussion of the findings and recommendations for further research.

2.0 THE ROLE OF DATA IN CIRCULAR SUPPLY CHAINS

Data is playing an increasingly important role in the CE transition and enabling new, more efficient, sustainable and inclusive ways of doing business (Luoma et al., 2021). SCs generate enormous amounts of data, and this data has to be collected and transformed into insights to improve the performance and efficiency of SCs ([illegible]ieri[illegible] et al., 2020). In recent years, CE approaches have been promoted as a solution for sustainability problems associated with SCs. In this context, circular manufacturing (CM) has been identified as an industrial manufacturing approach that adopts CE strategies such as circular design, cleaner production, remanufacturing and recycling (Acerbi and Taisch, 2020). Although the benefits of adopting CE principles have been widely discussed in the literature, CM still faces several barriers and challenges. In particular, data management and data dissemination have encountered difficulties (Ritzén and Sandström 2017; Acerbi and Taisch, 2020). In this regard, Acerbi and Taisch (2020) developed a framework encapsulating the relevant data in CM strategies based on three categories: product, process, and management (Table 13.1).

As illustrated in Table 13.1, data regarding product characteristics and disassembly is particularly important when aiming to achieve a circular design. Data collection during the design phase helps extend the product's lifecycle and enables reparability and maintenance services. Product use-phase data, on the other hand, impacts the design phase. This phase is very important since environmental impacts during a product's lifecycle depend on design-related decisions (Laurenti, 2015). Moreover, decisions concerning the materials used and the manufacturing processes implemented influence energy consumption and emissions during a product's life. At the other end of the product lifecycle, the disassembly strategy affects CM strategies such as remanufacturing, waste management, etc. Quantitative measures such as the number of operations, disassembly time and cost of resources (i.e. capital goods and human resources) provide valuable data to enable more efficient disassembly and have an impact on CM strategies (Marconi et al. 2017).

Furthermore, data collection on product composition impacts the recycling strategy by enabling materials evaluation in terms of recyclability or up-cyclability, which contributes to more efficient decision-making (Matsokis and Kirtisis, 2010). In this regard, analysis of the data is required to evaluate the social, economic and environmental impacts. Gathering and making sense of product use-phase data can lead to enhanced decision-making in the remanufacturing phase (He et al., 2020). On a different note, the reuse strategy requires data collection on product functionality and location (Alamerew and Brissaud, 2020). For waste management, collecting data on the types and volume of waste helps identify appropriate treatment methods and ways of reducing negative externalities (Álvarez and Ruiz-Puente, 2017).

In order to adopt an industrial symbiosis strategy, data collection is required for internal and external evaluations to find possible matching actors (Martín Gómez et al., 2018). Data concerning the types and volume of waste and/or by-products must be shared between partners to enable the sale or exchange of resources (Raafat et al., 2013). For a closed-loop SC and reverse logistics strategy, data collection on different SC actors as well as the logistical movements of materials/products is required to ensure the circularity of the resources. In terms of servitization, collecting data on consumers' behaviour and product use-phase condition helps in improving services and in some cases supporting and developing the product design (Spring and Araujo, 2017). Finally, data collection for resource efficiency and cleaner production strategy can contribute to tracking the environmental impacts of companies and the entire network (including suppliers).

Data transparency between SC partners improves supply and demand planning, production scheduling and delivery. Further benefits include end-to-end performance management and more efficient decision-making (McKinsey & Company, 2016). Data management throughout an SC improves transparency and visibility, uncovers hidden costs and eliminates redundant operations. Since SCs are associated with considerable complexity, developing effective data management capabilities will enable data integration and ensure a common language between

Table 13.1 Required data for CM strategies according to product, process and management ([illegible]marized from Acerbi et al[illegible]).

	Product	Process	Managerial
Circular Design	Product functionalities Product features Reparability	Material and energy used to produce and use product monitoring Disassembly time and costs	Maintenance service Material Procurement Supplier selection
Disassembly	Product disassembly possibility Product criticalities evaluation Components substitution possibility	Number of operations to reach a target component Time spent to reach a target component Labour and tools cost to reach a target component	
Recycle	Recyclable materials and components Quality utility value	Operation cost per unit Technique level Resource consumption efficiency	Employee turnover rate Brand reputation Local community influence
Remanufacture	Product conditions Market requirements Product type Product model	Monitor collection and remanufacturing processes costs Production plan scheduling balancing remanufacturing activities	Safety and ergonomics condition for workers Planning of remanufacturing processes Monitor time, quantity and quality
Reuse	Product functionalities	Transportation costs Collection costs Supply costs	Marketing Legislation respectfulness
Waste management	Product components Product materials composition Product material quality	Production process energy and material consumption Waste generation during production processes Energy consumption	Logistics Labour force Waste collection centres (location)
Industrial symbiosis	Toxicity of resources Cyclicity of resources Type and quantity of by-products and waste produced	Monitoring of physical system data during the conversion, such as temperature, flow rate, pressure, enthalpy, the concentration of chemical species of streams	Location of the entities collaborating in the industrial symbiosis Storage of information
Closed-loop supply chain and reverse logistics	Product condition Product value Product life cycle stage Product design	Disassembly scheduling and cost Life cycle assessment for an eco-report By-products monitoring	New environmental requirements for purchasing Design reverse logistic network Sustainable supplier selection

different partners (Yu et al., 2018). In return, this will enhance the development of CE strategies, as well as ensure customer satisfaction.

3.0 SUPPLY CHAIN ACTORS AND DATA UTILIZATION IN CIRCULAR SUPPLY CHAINS

Until recently, logistical networks have been characterized by a chain of processes flowing from primary material extraction to disposal of goods. However, this 'linear economic system' has proven to be unsustainable, and as a consequence, new areas of research have emerged such as reverse logistics, spare parts logistics, maintenance logistics, SC integration, closed-loop SC, etc. Since decisions in the forward logistics impact the solutions implemented in reverse logistics – a key component of circular business models and CSCs – it is essential to understand the current environment in terms of delivering value to customers.

Literature reveals that companies tend to outsource various SC functions or key activities across the stages of development, production and delivery of products/services. This might happen for various reasons including the wish to cut expenses, address the increasing complexity of SCs, or focus on core competencies (Kakabadse and Kakabadse, 2005). According to Langley and Infosys (2019, p. 8), revenues generated by the global logistics outsourcing market 'increased to $869 billion in 2017 from $804.2 billion in 2016'. Logistics outsourcing might be broadly defined as 'long and short-term contracts or alliances between manufacturing and service firms and third-party logistics [3PL] providers' (Rabinovich et al., 1999, p. 353). The strategic decision of subcontracting logistical functions goes hand in hand with the customer service strategy; finding a supplier that can provide logistics services or design/operate a reliable logistics system can increase customer satisfaction (Razzaque and Sheng, 1998).

Investigating the services offered by logistics service providers (LSPs), Muller (1993) differentiates between four types of actors: (1) asset-based companies that rely on internal assets such as trucks and warehouses to deliver physical logistics services; (2) management-based vendors that leverage systems databases to provide management support and consultancy services, thus enhancing the strategic positioning of their clients; (3) integrated vendors that can customize services based on the needs of their customers by leveraging both resource-intensive and information-intensive capabilities; and (4) administration-based companies that provide administrative services such as customs clearance and freight payment. Furthermore, Engelsleben (1999) differentiates between LSPs that are engaged in 'activities that are directly related to the physical flow of products' (e.g. core logistical functions and value-added activities) and those that deliver services 'not directly related to the physical flow of products' (e.g. management support and financial services) (Delfmann et al., 2002). These categorizations indicate that LSPs have increasingly focused on developing information-intensive capabilities to fulfil customer demands and stay competitive in the market. On the other hand, it can be noticed that the scope of logistics outsourcing has gradually evolved from execution of mediator functions to value-added and advanced services. These observations support the views of Karmarkar and Apte (2006, p. 438), who claim that there is a universal shift 'from a material-based economy to an information-based economy' (Karmarkar and Apte, 2006, p. 438).

Langley and Infosys's study (2019, p. 9) highlights that 'strategic and customer-facing activities tend to be outsourced somewhat less than those that are more tactical and operational'. However, with the increasing focus on CE transitioning, demand for management- and information-oriented logistics services is likely to increase. Monitoring lifecycle data to aid decision-making at [illegible] as well as measuring CE performance requires better data management and SC integration.

Exploring the literature on outsourced management- and information-oriented logistics services in the context of a CE, one can observe several different emerging themes. First, LSPs in a CE can enable the integration of processes within manufacturing sites and along SCs (Pedone et al., 2021). Such integration will enhance information sharing between the 'manufacturing and de- and remanufacturing operations' or the flows of forward and reverse logistics that are currently 'carried out independently and without sharing information and economic benefits' ([illegible] p. 70). In such a scenario, LSPs can perform [illegible] planning and scheduling with the support of integrated logistics information platforms. According to the same source, service providers' systems management capabilities allow them to perform supply and demand forecasting for remanufactured/repaired products and conduct economic assessments of circular business cases. In addition, such actors can also design responsibility sharing mechanisms among SC members (Shankar et al., 2018).

As highlighted earlier, outsourced logistics functions encompass multiple services. When monitoring the flow of a product through its lifecycle, it might be possible to identify several specialized LSPs performing at different stages, forming somewhat of a network of LSPs (Roth et al., 2014). An actor that can aggregate the demands of other LSPs and manage horizontal cooperation networks between them could enable e-commerce logistics systems that offer matchmaking services for excess capacity while designing optimum service systems to clients (Chabot et al., 2018, Li et al., 2022). In addition, with the increasing focus on distributed manufacturing and production-as-a-service, there is a need for an actor that can create intercompany relationships and 'orchestrate production services according to a product recipe' (Kuhn et al., 2020, p. 4). This actor would use 'information technologies [IT] such as big data/prescriptive data analytics, artificial intelligence or blockchain concepts, often in combined technology platforms' to integrate 'production, supply and consumption systems into an umbrella' (Melkonyan et al., 2019, p. 152). Following these examples, the second theme identified in the literature is network orchestration; actors with systems management, customer management and e-commerce capabilities manage the mapping and translation between the re[illegible] and network members that can satisfy these requirements ([illegible]., 2[illegible]

Data is also crucial for predictive maintenance (Niyonambaza et al., 2020). Collecting maintenance history data as well as raw data of sensors is necessary in this regard. According to Deb et al. (2019, [illegible]), service providers should 'reuse the existing knowledge and information about the customers and their past requirements [...] [and] maintain a reusable knowledge repository [...] on various tools to search readymade solution and prompt actions'. This information is related to a third theme identified in the logistics outsourcing literature: product life extension. Within this category it is important to mention that disassembling and restoring failed products/equipment to an operational state requires access to product-specific data; information-sharing between manufacturers and service providers is therefore an important performance driver. According to Janicke et al. (2020), however, more advancements in data analytics are required to be able to detect quality issues in SCs that are actively using second life components/product and to guarantee that repurposed devices/products retain their integrity while passing through different owners.

Finally, 'inspecting and sorting efforts can be augmented with technology and AI […] these systems can optimize routing of items for reprocessing in ways that extract maximum value and minimize material sent to landfill' (Wilson and Goffnett, 2021, p. 652). In this respect, LSPs handling products at end-of-life or those that manage reverse networks on behalf of clients can assure optimal destinations for returned products. The last theme identified in the literature is thus improved end-of-cycle handling. However, it is worth noting that asset-based vendors that facilitate logistical movements between SC actors might also collect important data about products in transit. These actors can rely on traditional tracking technologies.

As a final remark, it is worth noting that 'IT became the most controversial part of the outsourcing revolution' (Kakabadse and Kakabadse, 2005, p. 184). The same source indicates that IT could either contribute to the strategic and competitive position of firms or be perceived as a support service. This section detailed both instances. In addition, the authors of this chapter highlight that in a modern logistics industry underpinned by CE principles, both service offerings and data structures are becoming increasingly diverse and complex.

4.0 SUPPLY CHAIN 4.0 AND CE

According to McKinsey & Company (2016), 'Supply Chain 4.0 [is] the application of the Internet of Things, the use of advanced robotics, and the application of advanced analytics of big data in supply chain management: place sensors in everything, create networks everywhere, automate anything, and analyse everything to significantly improve performance and customer satisfaction.' Industry 4.0 technologies are disruptive and utilizing such technologies requires companies to rethink and redesign their SCs (Jabbour et al., 2018). The term 'Supply Chain 4.0' has been introduced by researchers to define the relationship between Industry 4.0 technologies and SCs and to emphasize the applicability and impacts of such technologies on transitioning to a CE. As highlighted in earlier sections, SCs generate large volumes of data, which should be managed and analysed accordingly to achieve CE goals. Since one significant aspect of Industry 4.0 technologies includes their capability to gather and analyse big data, such technologies can enable SC innovation as well as optimized logistics processes (Wang et al., 2016). McKinsey & Company (2016) defined six main value drivers for Supply Chain 4.0 improvements, as presented in Table 13.2.

Future CSCs will rely greatly on big data-driven supply chains. Big data enables precise and valuable information to be made available, which promotes effective decision-making (Gupta et al., 2018). Del Giudice et al. (202[illegible]) list 21 disruptive technologies that are related to SC 4.0 and CE. These include 'IoT, SP – smart products, SM – smart machines, CSB – cyber security and blockchain, AI, At – automation, BDA – big data analytics, CT – cloud technologies, M2M, RFID, ST – sensors technologies, Dt – digitalization, Rb – robotics, OS – optimization systems, BI – business intelligence, 3Dp – 3D printing, MA – mobile apps, ERP – enterprise resource planning, AR – augmented reality, OC – omni channel and Nt – nanotechnology'. These technologies enable greater transparency and better collaboration between partners within the SC and facilitate human–machine collaboration. BDA will thus have a significant impact on 'predictive analytics in demand' and 'closed-loop' in planning processes in SC 4.0. These technologies together with machine learning approaches and advanced algorithms can develop precise and concrete demand plans and improve forecasting accuracy by 30 to 50 per cent (Tseng et al., 2018). 3D printing, AI, SM and Rb technologies can increase product

Table 13.2 [illegible] value drivers for Supply Chain 4.0 (based on [illegible]

[illegible] Agility, Capital [illegible]					
Planning	Physical flow	Performance management	Order management	Collaboration	SC Strategy
Predictive analytics in demand planning	Automation of warehousing	Automated root cause analyses	Reliable online order monitoring	Supply chain cloud	Micro-segmentation
Closed-loop Planning	Autonomous and smart vehicles	Digital performance management	Real-time replacing	Ende-to-end/ [illegible] connectivity	Dynamic network configuration
Automation of knowledge work	Human[illegible]achine interfaces	Online transparancy	No-touch order processing		
Advanced profit optimization	Smart logistics planning algorithms				
Scenario planning	In site 3-D planning				

and service flexibility through automation and enhanced visibility of product behaviour. CT, IoT and Dt enable integration and close collaboration between all partners of the SC network. Utilizing these technologies enables information sharing internally as well as, externally, increasing the efficiency and effectiveness of CSC processes. Utilization of IoT and RFID technologies, which can gather real-time data on the performance of machines and production processes, will increase SC transparency (Mboli et al., 2020). Making sense of big data will enable more personalized and customized SCs. Additionally, utilizing blockchain technologies provides controlled and shared access to data as well as fosters the ability to trace and verify logistics movements as a commodity advance through the SC.

Centobelli et al. (2022) developed a blockchain-based CSC framework that includes the three aspects of trust, traceability and transparency. The framework describes blockchain platforms utilized in reverse logistics process; these are meant to enhance the performance of different waste/resource management practices such as recycling, redistribution, and remanufacturing. Integration of blockchain technology in the SC increases trust and allows traceability between partners through smart contracts. In addition, blockchain increases information velocity and elimination of distorted and inaccurate information, which increases transparency (Kshetri, 2018). This leads to improvement of SC management performance as well as reducing distribution system costs.

5.0 CASE STUDY ANALYSIS

Literature lacks practical examples illustrating the benefits of Industry 4.0 in CSCs (Taddei et al., 2022). However, clear evidence of the usefulness of Industry 4.0 in CSCs is essential for understanding how technologies may be used in real-world situations and for suggesting future improvement and development opportunities. According to the results of the survey conducted by Gartner (2020), for 786 organizations, four key technologies in CSC are: advanced analytics, 3D printing, IoT and machine learning.

Although few organizations used blockchain technology in their circular solutions for SC, 38 per cent of respondents mentioned to implement blockchain in CSC in the next five years. Therefore, for the case analysis in this section, the authors chose the cases that utilize three of the key technologies in CSCs; 3D printing, IoT, and blockchain. The second reason for case choices is related to the focus on utilizing data in their solutions. The first case involves the use of blockchain technology to enable the traceability of polymers in Porsche's SC. The second highlights the importance of cloud data and IoT for reducing waste and the use of 3D printing delivery trucks for increasing SC efficiency.

5.1 Case Study 1 – Enabling Polymer Traceability in the Porsche Supply Chain

The industrial sector is under increasing pressure from consumers, governments and civil society to assess and disclose the environmental challenges and issues posed by its operations. Manufacturers like Porsche are seeking to address these concerns by investing in new technologies that may offer improved resource traceability. In 2020, Porsche and Circularise launched the first blockchain traceability project in cooperation with Borealis, Covestro and Domo Chemicals. The aim of this project was to trace the polymer flow from raw materials to consumer applications with the intent to guarantee the use of sustainable materials in Porsche vehicle production. Overcoming the inherent complexities of the SC has proven to be a challenge, and various solutions were investigated to establish transparency while promoting trust, privacy and confidentiality (Circularise, 2020).

Circularise developed a blockchain-based SC traceability solution with a unique encryption technology called 'Smart Questioning' for use in public blockchains while protecting intellectual property, identity and business relations. This technology was used in the pilot project to create a blockchain capable of tracking batches of materials throughout the production process by creating a digital copy called a 'digital twin'. Before the polymer batch is shipped, it is necessary to verify the batch on the blockchain through an independent third party (UL Solutions). Once the digital twin has been created and verified, any SC actor with access rights to the data can retrieve this data by scanning a QR code on the shipping containers. SC partners update the digital twin, mimicking the physical SC and manufacturing processes (e.g. Borealis, Covestro and Domo Chemicals). The digital twin can include information like the date and time that the batch was created, the location of the batch, the identity of the creator and any other relevant information. This information can be used to track the batch of products as they move through the CSC.

There howeve a tension between protecting customer, supplier and producer privacy; this is one of the obstacles associated with sharing information along the SC. For example, the source of materials is an integral part of transparency for both manufacturers and customers. However, the material composition of a product may be a source of competitive advantage and suppliers may be unwilling to disclose such information. Through Circularise's Smart Questioning platform, it is possible to generate verifiable assertions on public blockchains without revealing the underlying data. In the Porsche case, this can aid Porsche in measuring the CO_2 footprint and other sustainability indicators like water usage. In addition, Porsche can make smarter decisions for future generations of vehicles by supporting end-of-life recycling options and providing material traceability. By disclosing the product's environmental impact, the company can assist consumers in making sustainable decisions.

Through a dedicated mobile application, users can access the digital twin of their car. Through the mobile app, not only can Porsche communicate information related to environmental benefits but can also promote environmentally responsible behaviour. The app's focus is on sustainability, with the purpose of enhancing interaction and fostering brand loyalty. Finally, the digital twin enables tracking of the vehicle's use-phase and performance-related data over time. This can be used to improve the vehicle's future design. The information flow between the SC partners in the Porsche material blockchain is depicted in Figure 13.1.

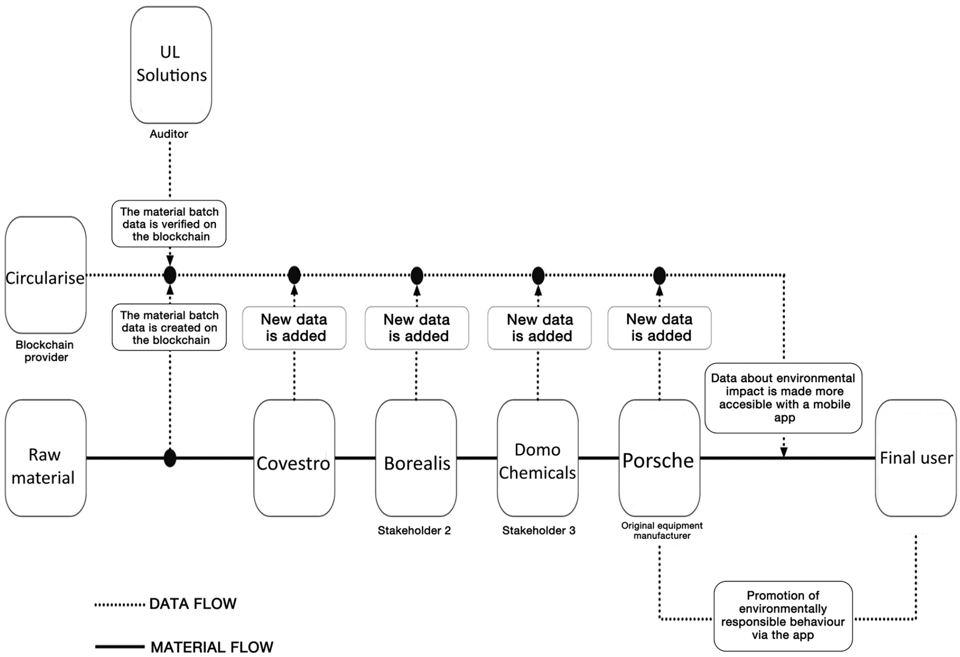

Figure 13.1: *C*[illegible] *of the Porsche blockchain (developed by the autho*[illegible]*a C*[illegible]

5.2 Case Study 2 – 3D printing Delivery Trucks: The Case of Amazon

The second case study focuses on Amazon's 2015 patent for 3D printing delivery trucks. This service has not been implemented yet but is worth investigating to get an indication of how data might be used to reduce time-to-market, decrease waste and enhance SC efficiency.

In 2015, Amazon filed a patent for the provision of services related to item delivery via 3D manufacturing-on-demand (Apsley et al., 2018). The patent describes a system in which products bought by customers are produced on-demand in trucks equipped with 3D printers while they are in transit (Figure 13.2). When a user places an order on Amazon's marketplace, the company transmits printing-related instructions to the user's nearest mobile production unit. As such, the mobile manufacturing unit aims to produce the order before reaching the end customer.

With this new approach, Amazon would be able to provide customers with a greater selection of goods, including personalized items, while shortening SCs. This additional service would diversify the company's current portfolio and alter its business model, which currently focuses on selling and delivering manufactured items. This new technology may present new opportunities for businesses in the future. Perhaps rather than selling products, they will commercialize product data such as computer-aided design CAD files, process parameters and material composition information (Geissbauer et al., 2017). The system would monitor the production status of each order and alert the user when their product is ready to arrive. Another opportunity for Amazon would be the manufacture of on-the-go spare parts (Bolaños et al., 2022). In other words, although Amazon's case does not solely focus on a CE, the underpinning technologies and business model could be leveraged to deliver the services needed to transition to a CE.

The authors of this chapter would like to emphasize that Amazon's innovative service idea of 3D printing delivery trucks is just a patent at this stage, and it is unclear whether Amazon plans to implement it at some point in the future. However, this system has the potential to eventually deliver items to customers in a more sustainable, efficient and cost-effective way. The role of data in this case study is to help Amazon reduce time-to-market, decrease waste and enhance SC efficiency. In the eventuality of the mobile 3D printing service being implemented, Amazon would use data to determine what products to print on-demand and how to print them. The system would also monitor the production status of each order and alert the user when their product is ready to arrive. Having access to customer-related data and IT capabilities, the company can estimate demand in a specific geographical area and at a specific time. The trucks can thus be mobilized before the user makes the order. In this way, the product may be delivered with a short lead time.

6.0 MANAGERIAL IMPLICATIONS

SCs are complex networks and organizations face huge challenges to implement CE solutions in their SC objectives and goals. According to the case study analysis of this chapter, digitalization of SC can help organizations make more sustainable decisions by tracking the flow of information alongside the product lifecycle. Collecting real-time data through sensors on components, systems and performance helps businesses provide more efficient services. Moreover, raw material suppliers can monitor the stock by logging into the manufacturer system and validate if certain materials reached to end. Consequently, the amount of waste produced in production and manufacturing processes will be reduced. In this regard, as discussed in the case of Porsche, blockchain has huge potential to enable traceability and tracking raw materials. A blockchain-based SC can help managers to track all necessary information on the products such as production time, location, identity of suppliers, etc. in real time. This enables transparency in the entire SC and leads to smarter and more efficient decision making on recycling of products and the choice of raw materials.

Furthermore, connected devices enables transferring data from customers and can help unlocking greater value through the entire SCs. It enables businesses to focus more precisely

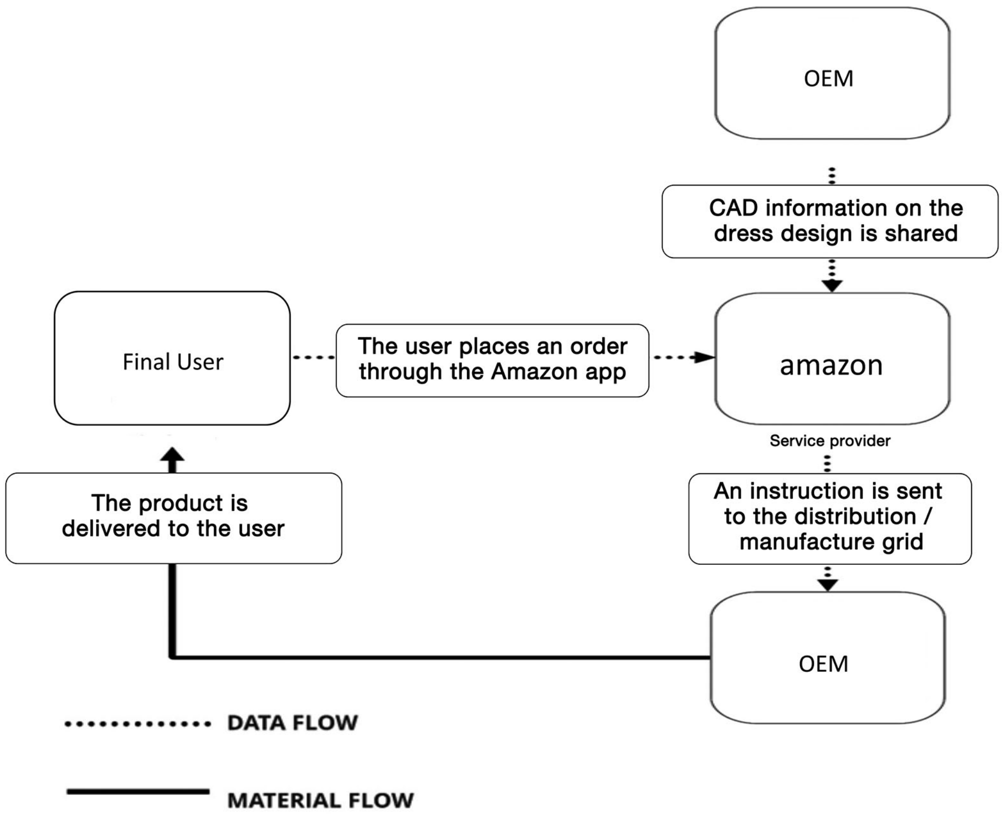

Figure 13.2: *Illustration of 3D-printed delivery truck operation (developed by authors based on Apsley et al., 2018).*

on consumers' demands and make more efficient delivery cycles with lower time and cost as well as reduced. As discussed in the case of Amazon, utilizing IoT and 3D printing helps mangers to offer more sustainable and customized products to the customers. By implementing these technologies in the SC, managers can offer services rather than products in a more cost-efficient way, with shorter delivery time and on-demand production. In this way the amount of waste and energy will be reduced as well.

In this context, it is worth mentioning that COVID-19 as well as other unexpected events such as the Suez Canal blockage put a spotlight on SCs across the world. However, CNBC (2021) note that SC chaos turned into a new business opportunity – during these unprecedented times, Amazon has taken steps to control as many nodes of the SC as possible to avoid delays and build resilience. In addition, Amazon has recently announced that as a continuation of the company's e-commerce success and significant investments in warehousing and distribution networks, a new service called Amazon Warehousing & Distribution (AWD) will now be available to sellers across the world (Daleo, 2022). ‘AWD makes the promise of supply chain as a service a reality and is specifically designed to solve inventory management challenges and deliver operational efficiencies’ (Pillai, 2022). This statement shows that Amazon is now a 3PL company. By investing in assets (e.g. warehouses, trucks, containers) as well as IT capabilities (e.g. Amazon Web Services, cloud technologies), Amazon can now leverage their infrastructure to become a leader in the logistics sector. With innovative ideas such as 3D printing in transit (as presented in the case study), they can revolutionize the services needed for a CE transition. This case study highlights the value of developing IT capabilities to deliver efficient and innovative (circular) logistics services.

7.0 DISCUSSION AND CONCLUSIONS

This chapter suggests that in spite of the importance of data in transitioning to a CE, theory and practice do not seem to conceive the use of digitally enabled technologies in the same way. The current literature is built on conceptual studies, and more empirical research is needed to explore the true value of developing IT capabilities with the intent of transitioning to a CE. In a CE setting, data enabling user monitoring of material provenance is crucial, and Porsche provides an excellent case to exemplify this. First, in a circular economy approach, it is essential to ensure that the materials used in Porsche vehicles are sustainable and can be reused or recycled. This helps to reduce the environmental impact of the company’s operations. Second, by tracking the materials used in its products, Porsche can ensure that its suppliers are using sustainable materials and that its products are made with minimal environmental impact. This helps the company to meet its commitment to sustainable business practices. Finally, by tracking the materials used in its products, Porsche can ensure that its products are of the highest quality and that they meet the company’s strict standards for safety and performance.

One key area in the transition towards ~~the circular economy~~ is the intelligent use of data. Utilizing AI technologies and BDA to predict consumer behaviour and trends is essential for developing products and services that match customers’ needs and to promote a longer ~~lifecycle.~~ Developing algorithms that can identify patterns in data is highly beneficial for optimizing product design and to improve the efficiency of manufacturing processes. For example, creating digital twins of products helps companies track their use and performance over time and makes it possible to identify ways to improve the product design and extend product life. To acquire the necessary real-time data from SC processes, there is a need to utilize modern measurement and sensor technology, such as IoT. Utilizing IoT to monitor and adjust production in real time can reduce waste and improve resource utilization and implementing IoT-based quality control systems can help identify defective products before they reach consumers. Efficient utilization of data is possible through effective data management and by implementing structured, verified and transparent data using Industry 4.0 technologies. Such data allows companies to reduce warehousing and operational costs and boost energy efficiency, and builds trust and a common language among SC actors.

On a different note, this chapter highlights that circular business models affect related service industries. Literature indicates that manufacturing companies tend to outsource some or all of their logistics functions. Thus, the contribution that the logistics sector can bring towards the scaling up of CE transitioning cannot be overlooked. Accordingly, the authors suggest that further research will benefit from more case studies and real case example analysis, which is lacking in the existing research on SC 4.0.

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