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SYNCHRONIZED BARRIERS FOR CIRCULAR SUPPLY CHAINS IN INDUSTRY 3.5/INDUSTRY 4.0 TRANSITION FOR SUSTAINABLE RESOURCE MANAGEMENT

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ABSTRACT

Transition from Industry 3.0 to Industry 4.0, in other words Industry 3.5 stage, and moving to a circular economy are two significant concepts for organizations that need to make wholesale alterations to their current systems. In order to stay competitive, both these transitions need to follow sustainable resource management and digital transformation principles. However, there are barriers to these changes that organizations should consider. Both Industry 4.0 transition, in other words Industry 3.5, and circularity transition require great efforts to deal with these barriers; in the current environment, organizations need to deal with these barriers simultaneously for more sustainable resource management. This study focuses in particular on circular supply chains in the Industry 3.5 stage. There are some studies that suggest barriers to Industry 4.0 and circular supply chains separately, none of these studies consider them together. From this point of view, this study contributes to existing literature by presenting synchronized barriers that integrate circular supply chain and Industry 4.0 barriers. Firstly, pillars of circular supply chains in Industry 4.0 are explained; synchronized barriers are then presented. A decision-making method, Fuzzy Analytical Network Process, is used to prioritize the synchronized barriers, with theoretical and practical implications proposed according to the result of the implementation.

1. Introduction

Nowadays, companies are facing two major pressures that may challenge their business models and have significant impact on their operations. The first pressure is the digitization that promises more efficient processes, cost minimization, higher reliability, effective design and improved control of management (Gupta and Gupta, 2018). Competitive strategies, such as differentiation and responsiveness, need effective and efficient management of supply chains because the speed, reliability and flexibility concepts are not limited to within the company but extend to the customer base and even to after sale services (Um, 2017). Therefore, Industry 4.0 or digitization enables the management and control of a system by taking a holistic view in order to manage the whole operation; thus, there is a need to transform from Industry 3.0 to Industry 4.0 (Chien et al., 2017a). However, this transformation is a long term plan and requires investment. Hence, most companies in the transformation stage can be regarded as companies in an Industry 3.5 stage (Chien et al., 2017b). Industry 3.5 can be seen as a hybrid strategy, not only for a technological transition in production systems, but also to manage any disruptive impact such as total resource management for sustainability (Chien et al., 2020; Yadav et al., 2020)

There is another important pressure i.e. sustainability of business, a crucial factor in recent years (Luthra and Mangla, 2018). Rapid growth in the world population has increased the importance of resource utilization for sustainability (Gorman and Dzombak, 2018; Islam and Managi, 2019). With this focus, plus concerns over climate change, diminishing resources and an increase in environmental pollution, an awareness of environmental concerns has grown in line with a sustainable resource management approach; this approach is seen as a method for solving these problems (Wu et al., 2019). Furthermore, achieving the triple bottom line dimensions of sustainability becomes an important issue for organizations (Agrawal and Singh, 2019). In this sense, social, economic and environmental sustainability should be incorporated within the company and in all stages of its supply chain (Ahi and Searcy, 2015). Thus, companies need to understand that profit maximization and cost minimization may no longer exist as the sole objectives of management.

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In addition, supply chain management should be considered as a crucial topic within sustainable resource management (Mota et al., 2015). In this perspective, circular economy, which can be used to minimize utilization of resources and decrease the waste generation (Abreu and Ceglia, 2018; Kalmykova et al., 2018; Bag et al., 2020), can be seen as a holistic and most appropriate way of how to transform the supply chain in the age of Industry 4.0. Integration of sustainable resource management, while developing high technological manufacturing environment, is now possible.

de Sousa Jabbour et al., 2018bDe Sousa Jabbour et al. (2018) defined the relationship between Industry 4.0 and sustainability as a synergy that makes an industrial wave and changes worldwide production systems entirely. In addition, Garcia-Muiña et al. (2018) stated that "Industry 4.0 and circular economy are candidates to be two sides of the same coin" to show the relationship between them. Furthermore, Tseng et al. (2018) suggested that Industry 4.0 approaches can be used to optimize sustainable solutions and empower a circular economy by reducing resource utilization and emissions caused by industrial activities. Similarly, Dev et al. (2020) stated that integration of Industry 4.0 and circular approaches such as reverse logistics operations can be implemented by adopting information sharing technologies, helping to spread sustainable products into the market. Moreover, Rahman et al. (2020) proposed that Industry 4.0 targets the social, environmental and economic dimensions of sustainability, and that investigation of technological developments from an economic perspective should be supported by social and environmental aspects. With the support of these views, it can be concluded that these transformations should be analyzed together. However, adaptation to Industry 4.0 processes in particular requires a huge alteration in both the infrastructure and workforce (Karadayi-Usta, 2019). A smooth transformation is needed especially for those companies with traditional production systems (Ku et al., 2020). Therefore, efficient solutions are needed while considering total resource management and digital transformation simultaneously. From this point of view, this adaptation process can be defined as the Industry 3.5 stage for organizations; this refers to a transitional stage from Industry 3.0 to Industry 4.0 (Chien et al., 2017). This paper also uses the term *Industry 3.5* to refer to the Industry 4.0 transition process.

However, there are many barriers for the circular and Industry 4.0 transition in sustainable resource management. There are barriers within so called Industry 4.0 transformation, in other words the Industry 3.5 phase, and there are barriers for circular supply chain (CSC) transformation. The crucial concept to emphasize is that the barriers within each transformation do not act independently, and similar to the opposite consequences of the synergy concept, these barriers may provoke, trigger and even amplify each other. Thus, it is a common phenomenon in many companies to complete these transformations simultaneously rather than one after the other because companies prefer to frame solution measures to handle these barriers at the same time. Therefore, it is necessary to address all the barriers, so called synchronized barriers, and their inter-relationships to achieve a successful transformation both in Industry 4.0 and CSC simultaneously for more sustainable resource management and digitalized structures.

Thus, it is necessary to answer the following research questions;

- What are the CSC barriers in Industry 4.0 transition i.e. Industry 3.5 for resource management?
- How are the relative priorities of these barriers determined?

In order to answer the aforementioned research questions, the barriers to the Industry 4.0 and CSC transformations should be scrutinized. In this study, proposed barriers will be prioritized by using a decision-making method, fuzzy Analytical Network Process (ANP), to guide managers on the most important barriers to deal with during the transition to CSC in Industry 4.0.

This study is structured as follows. Following the introduction, the theoretical background related to CSC barriers and Industry 4.0 barriers are given in Section 2. In Section 3, problem structure and proposed barriers for CSC in Industry 4.0 are presented. In Section 5, methodology and the prioritization of the barriers are stated. Section 6 includes the implications, and finally, Section 7 provides the conclusion.

2. Theoretical background

Theoretical background for this study includes two sub-sections. Firstly, CSC barriers, and secondly Industry 4.0 barriers, are presented. These barriers are the core of the proposed CSC barriers in Industry 4.0.

2.1. Circular supply chain barriers

Supply chain performance of a company directly affects the organizational performance (Govindan and Hasanagic, 2018; Corona et al., 2019). However, transition from linear to CSC is a challenging process for organizations (Levering and Vos, 2019; Schraven et al., 2019). Briefly, CSC refers to a recovering production system, where resources move into a continuous loop of end of life activities i.e. recycling, reuse and remanufacturing. This provides opportunities to overcome some global problems including resource scarcity, pollution, climate change, uncontrollable production and consumption (Mangla et al., 2018; Sehnem et al., 2019). In line with sustainability objectives, CSC considers sustainable resource management for more efficient resource utilization to protect environmental, social and economic gains.

Therefore, determining barriers against the circularity in the supply chain is essential for total transformation in terms of organizational, operational, managerial, technological and financial elements. Although barriers to a circular economy, sustainable supply chain management and green supply chain management are some of the research topics that are popular in current literature; barriers to CSCM for resource management have not received any in-depth attention.

When the challenges around CSC are investigated from the macro perspective, the major factor is revealed to be the transformation of the entire supply chain according to the main elements of circular economy. The Ellen MacArthur Foundation (2013) suggested that there are four of these elements namely "circular product design, servitised business models, reverse logistics and enablers". From this point of view, Bressanelli et al. (2018) stated that it is unlikely for a company to redesign the entire supply chain suddenly; it is more possible to focus on circular economy elements individually. They then conducted a systematic review related to challenges of supply chain redesign for circular economy.

Mangla et al. (2018) analyzed the barriers to CSCM with a special focus on emerging economies; they aimed to identify key barriers to CSCM, developing an interpretive structural model by examining the relationship between them to implement CSCM practices successfully. Similarly, Govindan and Hasanagic (2018) identified the main barriers, drivers and practices for the implementation of circular economy in a supply chain by conducting a systematic literature review.

Levering and Vos (2019) focused on processes to adopt and implement sustainable operations to achieve CSC, identifying drivers and barriers of CSCs for four different industries by including their current sustainable practices. Furthermore, Saroha et al. (2018) conducted a systematic literature review on identification of challenges around CSCM; these were categorized under governmental challenges, technological challenges, knowledge and skill challenges, management challenges, framework challenges, social challenges and market challenges. Their aim was to present an initial framework to understand CSCM challenges. Pan et al. (2015) especially focused on waste to energy supply chains and looked for ways to achieve circular economy by focusing on problems such as greenhouse gas (GHG) emissions, waste management and energy demand; they grouped barriers under technological, financial, institutional and regulatory aspects.

In Table 1, a summary of the CSC barriers that are presented in

Table 1
Summary of CSC barriers.

Lack of industry incentives for 'greener' activities	Mangla et al. (2018)
Lack of environmental laws and regulations	
Lack of Management commitment and approach for CSCM adoption	
Lack of preferential tax policies for promoting the circular models	
Lack of implementation of environmental management certifications and systems	
Lack of middle and lower level managers' support and involvement in promoting 'greener' products	
Lack of customer awareness and participation around CSC activities	
Poor demand/ acceptance for environmentally superior technologies	
Lack of technology transfers	
Inadequacy in knowledge and awareness of organizational members about CSCM initiatives	
Lack of appropriate training and development programs for SC members and HR	
Lack of effective planning and management for CSCM concepts	
Lack of systematic information systems	
Lack of coordination and collaboration among SC members	
Lack of support and participation of stakeholders	
Lack of economic benefits in short-run	
Transportation and infrastructure	Bressanelli et al. (2018)
Return flows uncertainty	
Availability of suitable supply chain partners	
Coordination and information sharing	
Product traceability	
Cultural issues (linear mind-set)	
Eco-efficiency of technological processes	
Product technology improvement	
Data privacy and security	
Lack of vision	Saroha et al. (2018)
Lack of laws and policies	
Lack of system standardization	
Higher investment cost	
Lack of funding	
High production cost	
Lack of knowledge	
Lack of follow up	
Lack of information sharing	
Lack of awareness	
Lack of skilled workers	
Lack of support of top management	
Lack of information on BAT(Best Available Technology)	Pan et al. (2015)
Technologies made locally available	
Difficulty of choosing cost effective technology	
Internal bureaucracy in creating circular logic in the supply chain	Levering and Vos (2019)
Measuring environmental impact (certification)	
Achieving transparency through stakeholders	
Costs of developing circular alternatives	
Lack of a standard system for performance indicators with regard to measuring CE in SC	Govindan and Hasanagic (2018)
Unclear vision in regards of CE in SC	
Weak economic incentives make it difficult for enterprises to implement CE in SC	
Major upfront investment costs in SC by implementing CE	
High costs are related to recycled materials in SC and therefore they are often more expensive than virgin in the market	
Technological limitations by tracking recycled materials	
It is difficult for enterprises to manage product quality through the lifecycle of a product	
Design challenges to reuse and recovery products	
Make the right decision in SC to implement CE in the most efficient way	
Accurate information regarding materials/tracking in SC towards recycling is not available	
Lack of skills by employees in CE	
Poor leadership and management towards CE in SC	
Organizational structure makes it difficult to implement CE in SC	
Lack of successful business models and frameworks to implement CE in SC	
Lack of enthusiasm towards CE in SC	

different studies are given.

In the following section, barriers to Industry 4.0 are presented after a study of the literature review.

2.2. Industry 4.0 barriers

The need for major changes in organizational structure and process reveals various barriers to Industry 4.0. The need for high investment (Glass et al., 2018; Engelbertinl and Woudstra, 2017; Zhou et al., 2015; Geissbauer et al., 2014; Colotla et al., 2016; Kamble et al., 2018; Karadayi-Usta, 2019; Aggarval et al., 2019) could be the first main barrier to Industry 4.0. A lack of clarity in defining any returns on investment (Geissbauer et al., 2014; Luthra and Mangla, 2018) adds to the challenge of attracting high investments. Unclear benefits of Industry 4.0 investments are mainly caused by lack of adaptability among organizations (Geissbauer et al., 2014).

Organizational acceptance of Industry 4.0 is only possible with clear understanding of its strategic importance. Dedication of the management in terms of providing knowledge management programs and training and education for employees is crucial for Industry 4.0 (Luthra and Mangla, 2018). However, lack of knowledge about Industry 4.0 triggers the barriers of underestimating the importance of Industry 4.0 and lack of top management support.

As Kamble et al. (2018) stated, virtual organizations using Industry 4.0 do not legally exist unless laws and regulations for data protections are presented. Therefore, the current unclear legal situation and laws concerning use of external data (Geissbauer et al., 2014; Aggarwal et al., 2019) is another barrier to Industry 4.0.

The nature of Industry 4.0 includes horizontal integration, where value-creating networks are revealed by integrating stakeholders; this leads to the need for protocols and standards for data collection and protection (Türkeş et al., 2019). Relatively brand new concepts in Industry 4.0 expose the need for a reference architecture, guideline or agreed standards (Kamble et al., 2018). In such an environment, lack of standards related to Industry 4.0 appear as one of the important barriers (Luthra and Mangla, 2018; Türkeş et al., 2019; Stentoft et al., 2019).

Transformation to Industry 4.0 requires not only technological investments, but also a transformation from employees in terms of how they work and their responsibilities. A significant change is to be expected in the role of a workforce due to the introduction of high technological machines in most of the traditional processes (Kazancoglu and Ozkan-Ozen, 2018). Therefore, companies should consider strategic approaches for human resources (Stachová et al., 2019). With this in mind, barriers related to the workforce appear as an important topic in current literature. These include requirements for advanced training and education (Stentoft et al., 2019; Engelbertinl and Woudstra, 2017; Türkeş et al., 2019; Karadayi-Usta, 2019) and a lack of skilled and qualified employees for the adaptation process (Glass et al., 2018; Stentoft et al., 2019; Tupa et al., 2017; Geissbauer et al., 2014; Colotla et al., 2016; Kamble et al., 2018; Müller et al., 2018; Karadayi-Usta, 2019). It is necessary to look at who has a suitable background to adopt advanced technologies in Industry 4.0 in order to tackle the barriers to Industry 4.0 related to employees. Understanding the importance of interaction between humans and machines is another issue that companies should deal with during the adaptation process to Industry 4.0 (Stentoft et al., 2019).

Cyber security is another significant challenge in Industry 4.0, since these technologies involve a high amount of data sharing and interconnection between stakeholders and processes (Aggarwal et al., 2019). Therefore, a high dependency on data security due to sensitivity and vulnerability of data plus inadequate data management is identified as a significant barrier to Industry 4.0 (Glass et al., 2018; Stentoft et al., 2019; Engelbertinl and Woudstra, 2017; Tupa et al., 2017; Zhou et al., 2015; Schröder, 2016; Geissbauer et al., 2014; Luthra and Mangla, 2018). Moreover, the need for monitoring and controlling the dynamic processes in an Industry 4.0 environment, reveals the importance of intelligent equipment and construction of network environment (Zhou et al., 2015; Chen et al., 2018). Therefore, companies should also prepare the infrastructure based on these needs.

In Table 2 a summary of the Industry 4.0 barriers are presented based on previous research.

In the following section, proposed CSC barriers to Industry 3.5/ Industry 4.0 for total resource management are presented.

3. Problem structure and the rationale for the proposed barriers

Industry 3.5 can be seen as a hybrid strategy to define the transition from Industry 3.0 to Industry 4.0; this includes disruptive innovations and integrated concepts such as digital decisions, smart supply chains and smart manufacturing (Chien et al., 2017b). As mentioned before, this study aims to define CSC barriers in Industry 4.0 and prioritize them. In order to do that, the pillars of the Industry 4.0 and CSC transformations should be examined. Fig. 1 exhibits these pillars and the relationships among them.

Whether Industry 3.5/ Industry 4.0 and CSC transformations are conducted simultaneously or not, the initial step should be the redesign of the supply chain network. Industry 4.0 is designed to assess the stakeholders, Key Performance Indicators (KPIs) and data extraction points, whereas CSCs seek to convert a linear flow of a supply chain into circular. Therefore, redesign of the supply chain network is based on achieving closed loop supply chains that will be managed by digitization for sustainability and total resource management goals.

The transformation of linear chains to CSC presents an increased complexity (Mangla et al., 2018). This increased complexity is a result of two factors; the first is the increased number of stakeholders within the CSC. Now, certain stakeholders evolve as a result of circular flow and reverse logistics. The supply chain network has been transformed to a closed loop with the paradigm behind the supply chain converted from cradle-to-grave to cradle-to-cradle (Kumar and Putnam, 2008). The second factor is the varying business models within the CSC that did not exist within the linear version. These are the stages within circular flow which are built on the 6Rs (redesign, reuse, refurbish, remanufacture, recycle, recover) circular economy. Therefore, supply chain management may struggle with the increased complexity within this transformation.

The structure of the decision-making mechanism within the supply chain management has been changed in line with the increased number of stakeholders and the complexity of the process (Manuj and Sahin, 2011). This structural change in t.he decision making mechanism depicts two features of the decision making - the increased number of decisions and the content of the decision making problem. As the supply chain transforms into a circular version the increased number of stakeholders causes a subsequent increase in the number of decisions that need to be made. In addition, the closed loop concept brings different objectives to decision makers that were not inherent within the linear flow, and circular approaches provides powerful conceptual supports for these systems (Tseng et al., 2019).

This phenomenon highlights the need to consider multiple

Table 2
Summary of Industry 4.0 barriers.

1	Lack of knowledge about Industry 4.0	Glass et al. (2018); Stentoft et al. (2019); Türkeş et al. (2019); Geissbauer et al. (2014); Colotla et al. (2016); Kamble et al. (2018); Luthra and Mangla (2018)
2	Lack of standards	Glass et al. (2018); Stentoft et al. (2019); Türkeş et al. (2019); Schröder, 2017; Geissbauer et al. (2014); Luthra and Mangla (2018); Yadav et al. (2020)
3	Lack of understanding of the strategic importance of Industry 4.0	Glass et al. (2018); Stentoft et al. (2019); Türkeş et al. (2019)
4	Required continued education and training of employees	Stentoft et al., 2019; Engelbertinl and Woudstra (2017); Türkeş et al. (2019); Karadayi-Usta (2019)
5	Lack of skilled and qualified workforce for adaptation to Industry 4.0 technologies	Glass et al. (2018); Stentoft et al., 2019; Tupa et al. (2017); Geissbauer et al. (2014); Colotla et al. (2016); Kamble et al. (2018); Müller et al. (2018); Karadayi-Usta (2019)
6	Required high investments	Glass et al. (2018); Engelbertinl and Woudstra (2017); Zhou et al. (2015); Geissbauer et al. (2014); Colotla et al. (2016); Kamble et al. (2018); Karadayi-Usta (2019); Aggarval et al. (2019)
7	High dependency on data security due to sensitivity and vulnerability of data and insufficient data management	Glass et al. (2018); Stentoft et al. (2019); Engelbertinl and Woudstra (2017); Tupa et al. (2017); Zhou et al. (2015); Schröder, 2017; Geissbauer et al. (2014); Luthra and Mangla (2018); Aggarval et al. (2019)
8	Lack of management support for Industry 4.0 transformation	Glass et al. (2018); Geissbauer et al. (2014); Luthra and Mangla (2018); Aggarval et al. (2019)
10	Lack of clarity in defining return on investment	Geissbauer et al. (2014); Luthra and Mangla (2018)
11	Requirements of intelligent equipment and construction of network environment	Zhou et al. (2015); Chen et al. (2018)
12	Unclear legal situation and laws concerning use of external data	Geissbauer et al. (2014); Kamble et al. (2018); Aggarval et al. (2019)

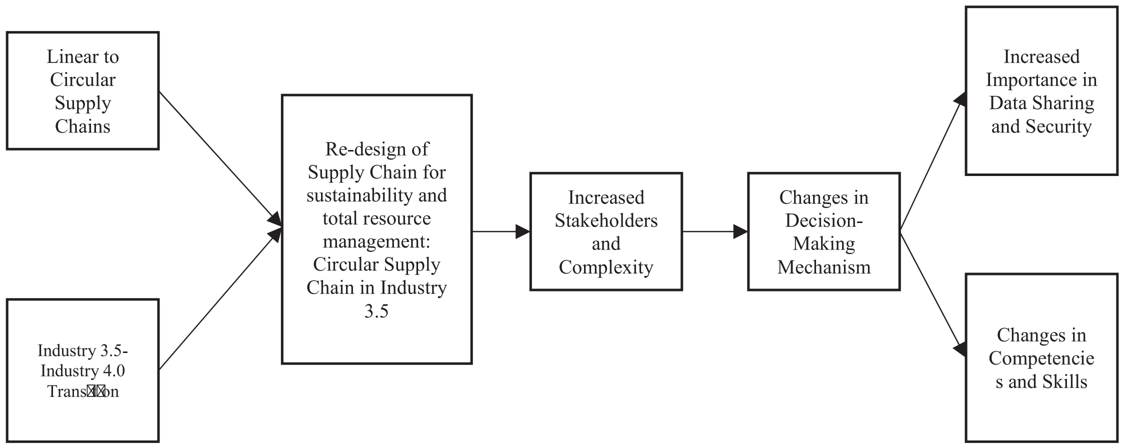

Fig. 1. Generic structure of circular supply chains in Industry 4.0.

objectives at the same time, as mentioned in Triple Bottom Line (TBL), within the same problem. Consequently, the nature, skills and competencies of the decision makers need to transform accordingly. These skills should be in line with the requirements of Industry 4.0 (Lorenz et al., 2015). Hence for those companies in Industry 3.5, the transformation will be reflected within the human resources of the company. They must recruit people equipped with the necessary skills and competencies who simultaneously can enhance the capabilities of their current human resources.

As a result of increased complexity within the supply chain, the varied content and a greater number of decisions to be made, the success of management becomes more dependent on decision making. Correct decision making becomes much more critical than before. The decision making process needs to be investigated in a deeper sense. Thus, the need for data interchange is essential as it will enable the transformation to both Industry 4.0 and CSC. Therefore, data sharing and security of the data plays a crucial role. The redesign of the supply chain should rely on data sharing in order to fulfill the requirements of both Industry 4.0 and the circular economy at the same time.

3.1. Proposed synchronized barriers to csc in industry 4.0 transition

Based on the given information, 13 synchronized barriers for CSCs in Industry 4.0 are proposed as a result of a literature review and a focus group discussion. The group was composed of four academics and four practitioners who work on Industry 4.0 transition and circular economies.

3.1.1. Lack of knowledge about data management among stakeholders (C1)

In linear economy, the number of stakeholders is not so high and relationships among them are usually one sided. However, with the transition to circular economy, the complexity of the chains increases tremendously, resulting in a greater need for data management skills. Digital technologies derived from the new industrial revolution could be useful to manage data sharing between an increased number of stakeholders with more complicated relationships (Mangla et al., 2018); however *lack of knowledge about data management among stakeholders* is revealed as an important barrier to CSC in Industry 3.5/Industry 4.0 transition.

3.1.2. Lack of understanding of decentralized organizational structure for supplier collaboration (C2)

Decentralized organizational structure is one of the key elements of the new industrial revolution as it encompasses internal and external processes in organizations entirely (Marques et al., 2017; Yadav and Singh, 2020). Therefore, CSCs should adapt the principles of decentralization in terms of decision-making mechanisms for more sustainable resource management. However, organizations now tend to follow central organizational structures; therefore *lack of understanding of decentralized organizational structure for supplier collaboration* can be stated as a barrier.

3.1.3. Lack of IoT (Internet of things) facilities for product tracking and recovery (C3)

Circular chains need advanced product tracking and recovery that covers the entire life cycle of the product (Bressanelli et al., 2018). When digital technologies in the new industrial revolution are considered, IoT is revealed as one of the most important pieces of technology for traceability. Therefore, IoT is a key element in CSCs; hence, during circular transformations, the need for suitable infrastructure should be considered. Therefore, *lack of IoT facilities for product tracking and recovery* could be a barrier to Industry 3.5/Industry 4.0 transition in CSC.

3.1.4. High investments in industry 4.0 technologies underpinned by uncertain nature of circular flows (C4)

In order to transform to a CSC, current supply chains should be redesigned by considering needs of circularity, i.e. sustainability and total resource management. It should be converted into a closed loop chain. This transition should be conducted in parallel with the Industry 4.0 transition. Both these transitions require high investments (Glass et al., 2018; Levering and Vos, 2019). However, return of investment is mostly unknown and the uncertain nature of circular flows increases the risks of these investments. Therefore, *high investments in Industry 4.0 technologies underpinned by uncertain nature of circular flows* can be presented as a barrier to CSCs in Industry 4.0.

3.1.5. Lack of knowledge in industry 4.0 technologies and circular approaches (C5)

Both Industry 3.5/Industry 4.0 and circular transitions require a new knowledge structure (Saroha et al., 2018; Luthra and Mangla, 2018). Decision making mechanisms within these transitions do not only need a greater number of decisions to be considered, but also a greater variety. Therefore, technological and circular skills must alter according to these changes, so that new competencies and skills are needed. From this point of view, *lack of knowledge in Industry 4.0 technologies and circular approaches* can be presented as a barrier to managing problems related to Industry 4.0 and circular knowledge.

3.1.6. Lack of integration to manage technology transfers in a circular chain context (C6)

CSCs include more complex stakeholder relationships when compared with linear economy principles. Moreover, the number of stakeholders increases since end of life cycle activities are regular parts of the

CSCs. All these requirements reveal the importance of technology transfers in CSCs in order to manage the increased variety and size of interactions (Mangla et al., 2018). Therefore, *Lack of integration to manage technology transfers in a circular chain context* is a barrier related to managing integration of technology transfers between stakeholders in Industry 3.5/Industry 4.0 transition in CSCs.

3.1.7. Lack of awareness in potential benefits of autonomous systems in labor-oriented end of life (EoL) activities (C7)

Automation in processes is one of the building blocks of Industry 4.0 transition. When integrated with circular transition, not only regular production processes but also labor oriented EoL activities such as disassembly, dismantling and recycling can be conducted with autonomous systems (Yang et al., 2018). However, *lack of awareness in potential benefits of autonomous systems in labor oriented EoL activities* limits the implementation of these systems, especially in the Industry 3.5 stage in organizations and therefore, can be stated as a barrier.

3.1.8. Poor management support in usage of industry 4.0 technologies in research and development (R&D) activities for "design for reuse" philosophy (C8)

Design for reuse is an important philosophy for sustainability and total resource management; it is highly related with circular approaches. In order to apply design for reuse, the R&D processes should embrace the philosophy and all design phases should consider the EoL of the product. Industry 4.0 technologies, such as 3D printing, enable R&D activities to become more efficient and more environmentally friendly. Hence, using Industry 4.0 technologies in R&D for circular goals could be very beneficial for organizations. However, *poor management support in usage of Industry 4.0 technologies in R&D activities for "design for reuse" philosophy* is a barrier to these benefits.

3.1.9. Inefficient training and education programs for human-machine interaction in circular operations (C9)

Transformation to CSCs and Industry 4.0 simultaneously needs new skills and competencies (Mangla et al., 2018). These two major transformations have mutual benefits but also some common requirements. In particular, human-machine interaction under the Industry 3.5/Industry 4.0 transition can be beneficial for circular operations. However, detailed and efficient training and education programs are required in order to manage this transformation successfully. Therefore, *inefficient training and education programs for human-machine interaction in circular operations* are barriers related to skills and competencies.

3.1.10. Lack of adoption of industry 4.0 technologies for higher transparency in circular flows (C10)

Transparency is an obligation in circular flows, due to the interrelated processes during entire lifecycles. In order to increase transparency, Industry 4.0 technologies, especially IoT and Blockchain, can be very useful. These technologies can improve communication among stakeholders, contribute to sustainability and total resource management, enhance efficiency in data sharing and contribute to the decentralized structure. Therefore, *lack of adoption of Industry 4.0 technologies for higher transparency in circular flows* is a barrier to the benefits of these technologies.

3.1.11. Issues related to data security in relationship management in circular flows (C11)

In the field of sustainable resource management, huge amounts of data have an increased value for both the organizations and environment (Song et al., 2019). The increased number of stakeholders and higher complexity in CSCs highlight the importance of data security. In view of the Industry 3.5/Industry 4.0 transition in these circular flows, data driven technologies play an important role (Geissbauer et al., 2014; Luthra and Mangla, 2018). Data security is not only an internal issue for the company, but it is important for all stakeholders in the CSC. Therefore, *issues related to data security in relationship management in circular flows* can be presented as a barrier that organizations should consider.

3.1.12. Lack of governmental regulations and support for industry 4.0 in circular environment (C12)

Regulations related to Industry 4.0 and the circular economy are not clear yet, since both are new concepts. Organizations need government regulations as guidelines for the transition to Industry 3.5/Industry 4.0 in a circular environment to gain environmental, economic and social advantages in terms of more efficient resource utilization. However, there is an uncertain environment related to these regulations (Kamble et al., 2018; Aggarval et al., 2019). Hence, *lack of governmental regulations and support for Industry 4.0 in the circular environment* is a barrier to CSCs in the new industrial era.

3.1.13. Lack of organizational willingness and trust in transformation of industry 4.0 and circular flows (C13)

Transition from linear to circular flows requires redesigning the supply chain network while embracing a sustainable point of view. Conducting this with an Industry 4.0 transition simultaneously, requires a significant change in all processes. Since these two concepts are very new, there are no solid examples to be used as guidelines during transition; suggested models are mostly theoretical. Therefore, organizations do not fully trust these new concepts and are not willing to change their culture entirely (de Sousa Jabbour et al., 2018). From this point of view, *lack of organizational willingness and trust in transformation of Industry 4.0 and circular flows* is an important barrier to this transition.

4. Methodology

Adopting Industry 4.0 to stay in the market and protect competitive advantages is essential for organizations. However, transformation from linear to CSCs while adopting Industry 4.0 technologies is a challenging process. Therefore, it is important to define CSC barriers in the Industry 4.0 environment and prioritize them to show the most important concepts during this transition. To achieve this, fuzzy Analytical Network Process (ANP) is used as a solution methodology in this study for weighting the criteria and prioritizing them. In Fig. 2, a flow diagram for the study is presented.

As can be seen from Fig. 1, the proposed methodology for this study starts with the literature review related to CSC and Industry 3.5/Industry 4.0 barriers separately; these are presented in Sections 2.1 and 2.2 respectively. After that, a generic structure for CSC in Industry 3.5/Industry 4.0 is presented. This is followed by a focus group discussion to propose and analyze synchronized barriers for CSC and Industry 4.0. As previously mentioned, a fuzzy ANP method is selected as a method for prioritization of the barriers. In the following section, details of the fuzzy ANP method are presented.

4.1 Fuzzy ANP method

The ANP method is the extension of Analytical Hierarchy Process (AHP), dealing with dependence within criteria i.e. inner dependence and among different criteria i.e. outer dependence (Chen et al., 2018; Mokarram et al., 2020). The ANP method is used for evaluation of all relationships systematically by considering potential interactions, feedbacks in decision-making systems and inter-dependencies (Farias et al., 2019; Tirkolaee et al., 2020). In short, the ANP method replaces hierarchies in AHP methods with networks as firstly described in 1980 by Saaty (Saaty, 1996).

In order to deal with the uncertainties and vagueness in human perceptions and judgements, it is more useful to use fuzzy numbers instead of definite numbers; therefore, integration of fuzzy logic and the ANP method, as well as using fuzzy ANP is beneficial in a fuzzy

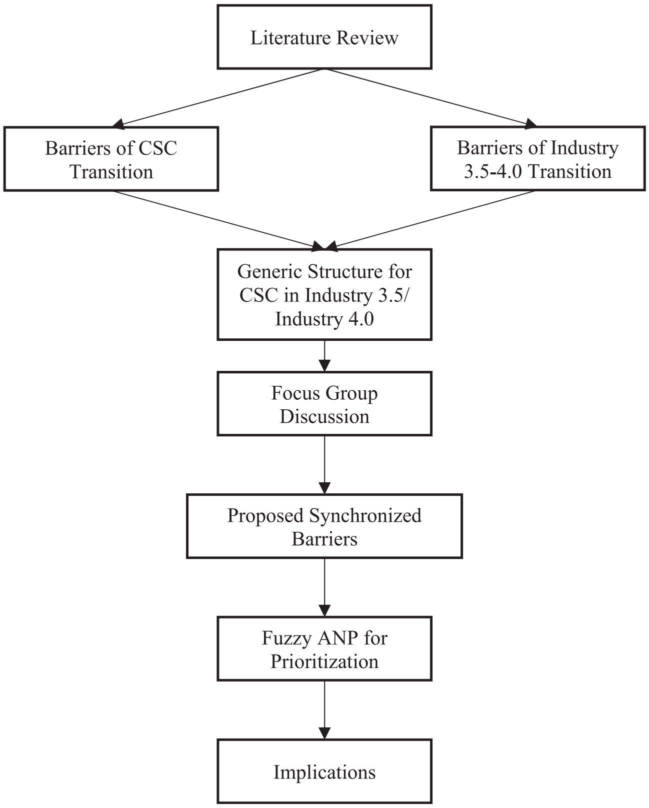

Fig. 2. Methodology of the study.

environment (Büyüközkan and Çiftçi, 2012; Mistarihi et al., 2020). In this study, a fuzzy ANP method is used to calculate weights of the CSC barriers identified in the Industry 4.0 environment.

Fuzzy logic is integrated into the ANP method by using triangular fuzzy numbers during the pair-wise comparisons of the criteria. The ANP method includes two main parts; these show relationships between criteria and a network of influence between criteria and alternatives (Saaty, 2001). Since the aim in using fuzzy ANP method is calculating the weights of criteria in this study, only the first part is going to be used. The ANP method has four main steps, summarized from Chung et al. (2005). These steps are; (1) Construction of the model and structuring the problem, (2) Pairwise comparisons of matrices and priority vector, (3) Formation of super-matrix and (4) Selection of the best alternative.

In fuzzy ANP, pairwise comparison matrices are shaped between different attributes at different levels with the use of triangular fuzzy numbers, where the idea of super matrices are used for obtaining composite weights, which overcome the current inter-relationships

In this study Önüt et al. (2009) is referred to in order to present application of fuzzy ANP. As mentioned before, in order to understand the perceptions of decision makers related to CSC barriers in Industry 4.0, a fuzzy linguistic scale is needed. In this study, triangular fuzzy numbers and expressions presented in Table 3 are used.

In order to evaluate preferences of decision makers, pairwise comparison matrices are structured by using values (l, m, u) in Table 3. By comparing criteria i with criteria j, where $i = 1, 2, 3, \ldots, n$, and $j = 1, 2, 3, \ldots, m$, the m x n triangular fuzzy matrix is found as below (Ramik, 2006):

$$\tilde{A} = \begin{pmatrix} c_{11}^l, c_{11}^m, c_{11}^u & \cdots & c_{1n}^l, c_{1n}^m, c_{1n}^u \\ \vdots & \ddots & \vdots \\ c_{m1}^l, c_{m1}^m, c_{m1}^u & \cdots & c_{mn}^l, c_{mn}^m, c_{mn}^u \end{pmatrix}$$

The element in the given matrix c_{mn} shows the comparison of criteria m (row element) with criteria n (column element); $\tilde{A}$ is the pairwise comparison matrix, which is reciprocal; the reciprocal value i.e. $1/c_{mn}$, is assigned to the element $\tilde{c}_{mn}$.

$$\tilde{A} = \begin{pmatrix} 1, 1, 1 & \cdots & c_{1n}^l, c_{1n}^m, c_{1n}^u \\ \vdots & \ddots & \vdots \\ \frac{1}{c_{m1}^l}, \frac{1}{c_{m1}^m}, \frac{1}{c_{m1}^u} & \cdots & 1, 1, 1 \end{pmatrix}$$

In order to estimate fuzzy priorities, where $\tilde{w}_i = w_i^l, w_i^m, w_i^u$, $i = 1, 2, 3, \ldots, n$ from $\tilde{A}$, which approximates the fuzzy ratios $\tilde{c}_{ij}$ so that $\tilde{c}_{ij} \approx \tilde{w}_i / \tilde{w}_j$. There are different methods. In this study, the logarithmic least squared method is used, as given below:

$$\tilde{w}_i = w_k^l, w_k^m, w_k^u \quad k = 1, 2, 3, \ldots, n$$

where,

$$w_k^s \frac{\left(\prod_{j=1}^n c_{kj}^s\right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n c_{ij}^m\right)^{1/n}}, \quad s \in \{l, m, u\}$$

After that, defuzzification is going to be carried out by following Opricovic and Tzeng's (2003) method. In the following section, details of the fuzzy ANP implementation are presented.

4.2 Application and results

Application of the study was conducted by the participation of five experts, with a minimum ten years experience, from different industries. All experts work in managerial positions in different departments. Industries are selected based on the need for circular economy principles and Industry 4.0 transition. In Table 4, details of the experts are presented.

These experts were asked to evaluate 13 barriers by using the linguistic scale that was presented in Table 3. In Table 5, an example of an evaluation matrix is presented.

After that the evaluations of experts are firstly converted to fuzzy numbers by using Table 3. Then the geometric mean is used to gather evaluations of experts. Fuzzy criteria weights are then determined as shown in Table 6.

Finally, the CFCS method is used for defuzzification with defuzzified criteria weights determined as given in Table 7.

From Table 7, the most important barriers are found as (C1) Lack of knowledge about data management among stakeholders, (C2) Lack of understanding of decentralized organizational structure for supplier collaboration, (C4) High investments in industry technologies underpinned by uncertain nature of circular flows, (C5) Lack of knowledge in Industry 4.0 technologies and circular approaches) and (C3) Lack of IoT facilities for product tracking and recovery. The results show that the first five barriers dominate the barrier group.

In Fig. 2, results of the fuzzy ANP implementation are summarized. As can be seen, the top five barriers constitute more than 85% of the entire results.

In the following section, implications and discussions are presented based on the most important five barriers.

5. Discussion and implications

The results have shown that more than 50% of the priority items are assigned to two barriers “Lack of knowledge about data management among stakeholders” (C1) and “Lack of understanding of decentralized organizational structure for supplier collaboration” (C2).

The barrier with the highest priority is “The lack of knowledge about data management among stakeholders” (C1) with an emphasis on data management. The data among the supply chain stakeholders constitutes a huge amount; when the reverse logistics operations are considered, both the type and variety of data increases meaning that the term ‘big data’ can easily be used (Xu et al., 2019). Moreover, as

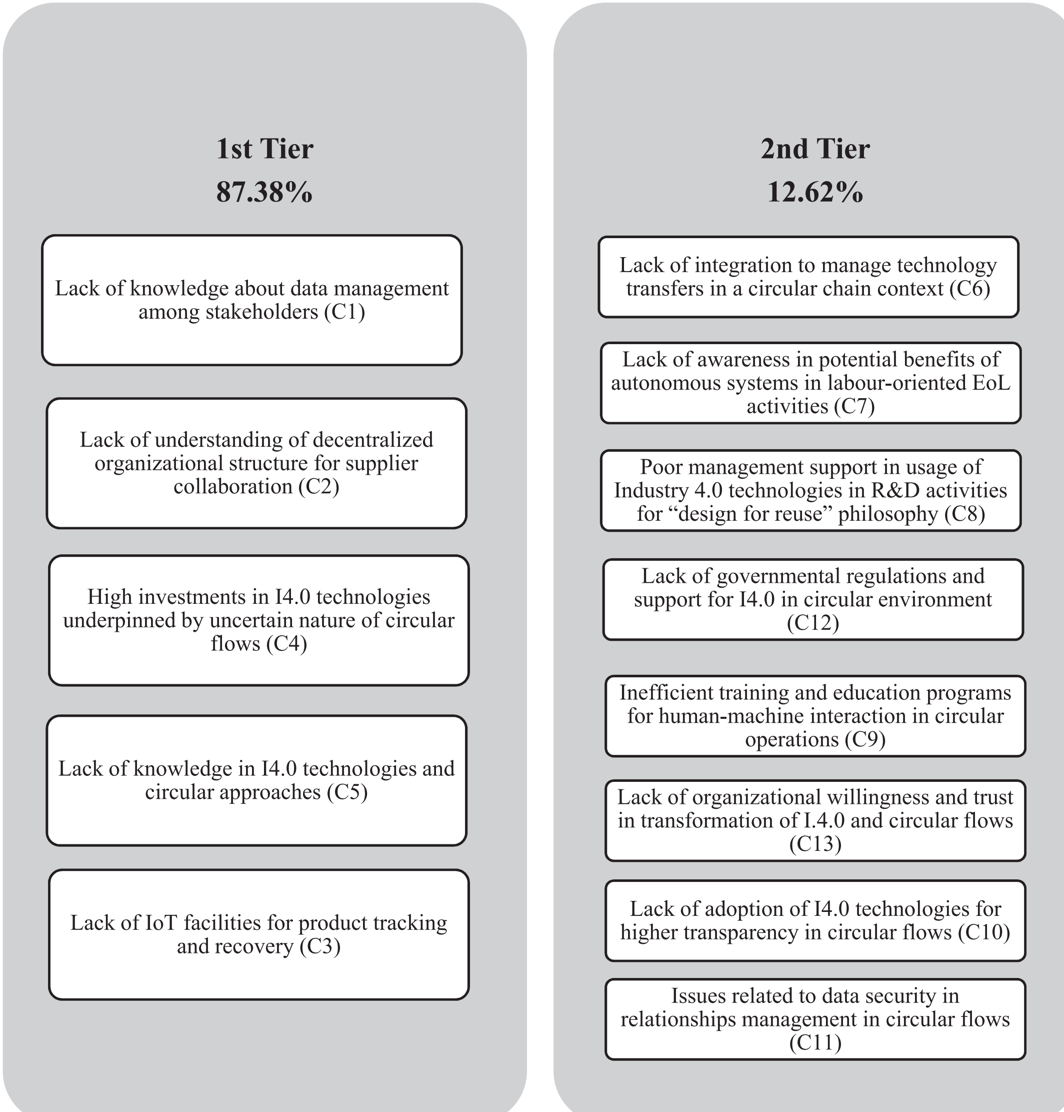

Fig. 3. Results of the Fuzzy ANP.

Table 3
Linguistic Scale.

Linguistic Expression	Triangular Fuzzy Scale *(l, m, u)*	
Equally Important (E)	(1, 1, 1)	(1, 1, 1)
Weak Importance (W)	(2, 3, 4)	(1/2, 1/3, 1/4)
Strong Importance (S)	(4, 5, 6)	(1/4, 1/5, 1/6)
Demonstrated Importance (D)	(6, 7, 8)	(1/6, 1/7, 1/8)
Absolute Importance (A)	(8, 9, 10)	(1/8, 1/9, 1/10)

Table 4
Details of experts.

Expert	Industry	Position	Year of Experience
1	Textile	Production Manager	26
2	Plastic	Supply Chain Manager	22
3	Electronic	Production Manager	18
4	Logistics	Operations Manager	20
5	Recycling	Operations Manager	14

Table 5
Example of one expert's evaluation.

Song et al. (2019) suggested, management of large-scale data would contribute to industry and businesses by highlighting sustainable resource management and green innovation.

The existence of big data leads managers to search for new and innovative ways to manage this extreme amount of data. Thus, management should focus on data analytics and should strive for ways to implement data analytics throughout the chain. However, it is not possible to implement data analytics without human resources that are equipped with the skills and competencies related to data analytics (Blackburn et al., 2017). Hence, the company should investigate how to gain the related skills and competencies necessary for data analytics by either educating the current workforce or recruiting new staff.

In addition, as mentioned within the barrier, it is not enough to equip the company with skills and competencies required by data analytics; this aim should be extended to all stakeholders throughout

Table 6
Fuzzy Criteria Weights.

	l	m	U
C1	0.254	2.282	2.664
C2	0.204	1.755	2.081
C3	0.099	0.763	0.842
C4	0.106	0.829	0.937
C5	0.097	0.758	0.877
C6	0.035	0.255	0.290
C7	0.024	0.178	0.206
C8	0.020	0.137	0.157
C9	0.010	0.069	0.081
C10	0.009	0.049	0.056
C11	0.004	0.024	0.028
C12	0.018	0.074	0.086
C13	0.007	0.041	0.043

Table 7
Defuzzified Criteria Weights.

	Un-normalized Weights	Normalized Weights
C1	1.9475	0.3074
C2	1.5146	0.2391
C3	0.6698	0.1057
C4	0.7294	0.1151
C5	0.6750	0.1065
C6	0.2409	0.0380
C7	0.1710	0.0270
C8	0.1331	0.0210
C9	0.0682	0.0108
C10	0.0481	0.0076
C11	0.0241	0.0038
C12	0.0730	0.0115
C13	0.0408	0.0064

the supply chain. However, it may not be possible to achieve this transformation beyond the borders of the company. Thus, data analytics will not be seen as a company specific competency but should be highlighted as a common language to be achieved among the stakeholders. Therefore, management should consider data analytics as a key element in establishing cooperation and collaboration among stakeholders. Management should present, promote and disseminate data management and data analytics in all related platforms where it is possible to have interactions with the stakeholders. In addition, it is possible that management may suggest the concept of data analytics as a requirement for its suppliers to enhance their sustainable approaches during Industry 3.5/Industry 4.0 transition.

The barrier with the second highest priority is "Lack of understanding of decentralized organizational structure for supplier collaboration" (C2,) highlighting the decentralization concept. As the supply chain increases, both the number and variety of decisions to be made expands; when the reverse operations are considered the number and variety of decisions may even double. The complex, dynamic and uncertain nature of CSCs requires new and innovative decision-making processes, especially to manage resources in a more sustainable way. The decision-making mechanism must change and transform to a more analytic and holistic nature. Furthermore, as mentioned earlier in this section, the human factor is again exhibited as a crucial factor. Those managers who are given responsibility for decision making should have certain capabilities and competencies. They should be good at analytical thinking, embracing systems approaches and capable in data management. Hence, a human resources program is crucial in terms of recruiting, educating and sustaining improvement in management.

As responsiveness emerges as a competitive advantage for companies, the need for speed and reliability increases; eventually the time pressure for decision making means that central decision making is not feasible. In such a system, it is not possible to overcome problems through centralization. This necessitates the capability to delegate decision making mechanisms all through the supply chain. Thus, delegation of decision making processes is another important implication for managers.

Finally, companies should identify solutions starting from their organizational structure. Companies should transform to matrix organizations to enhance decentralization. Matrix organizations can easily contribute to interdisciplinary and joint decision making processes with the aid of today's information and communication technologies. However, CSC brings additional requirements, such as working and cooperating with many different companies and organizational structures. Therefore, matrix organizational structures should be reconstructed and redesigned to go beyond the borders of a single organization. New business models should be established among different entities of the supply chain working for common objectives based on the matrix structure.

The common phenomenon about both barriers is that they require structural transformation. The implications mentioned above are crucial for structural transformations related to organizational structure and data management; these will have an important role to deal with these barriers in tandem.

The third barrier is "High investments in Industry 4.0 technologies underpinned by uncertain nature of circular flows." (C4) The main underlying concept in this barrier is the additional uncertainty of CSCs associated with the high investment requirements of Industry 4.0 technologies; investments can seem even less attractive. The uncertainty is mainly the result of increased variety and amount of flows supported by the lack of awareness of stakeholders towards circular flows. Thus, managers should use forecasting and predictive analytics to cope with the vagueness of the flows within CSCs. Smart production practices in Industry 3.5 that deal with uncertainties can empower more efficient resource utilization and production planning (Jamrus et al., 2020).

The fourth barrier is "Lack of knowledge in Industry 4.0 technologies and circular approaches." (C5) In line with the implications mentioned for the first barrier, the education and training of the current employees is important in dealing with this barrier (Türkeş et al., 2019). The education and training programs can be designed, planned and organized to exhibit the use of IoT applications within a circular economy to spread sustainability thinking during the Industry 3.5/Industry 4.0 transition. Further, the design and planning of educational programs should be extended in order to include the stakeholders along the supply chain, including reverse flows.

The fifth barrier is "Lack of IoT facilities for product tracking and recovery." (C3) The increased number of stakeholders within CSC demands the existence of trust among them. However, tangible and quantitative terms are necessary to build and enhance trustworthiness among various stakeholders. Therefore, information transparency is an important point and, IoT technologies will enable the tracking, tracing and recovery throughout the CSC.

To sum up, the implications related to the first and second barriers should be implemented initially. Only after these structural transformations are in place, can the company proceed to other areas. Therefore, data management and decentralization should be the initial aims of management in order to deal with the synchronised barriers.

When these results are compared with previous studies, some differences appear. This is to be expected since this study covers CSC and Industry 4.0 barriers in a synchronised way. For instance, according to the results of Luthra and Mangla (2018), lack of governmental support and policies was found to be the most important criteria under the strategic dimension; on the other hand, in this study, lack of governmental regulations and support for Industry 4.0 in circular environment (C12) was not included in the top five barriers. Results of this study were found to be similar to Luthra and Mangla (2018) in terms of financial constraints and lack of understanding in Industry 4.0. Legal and contractual uncertainty was found to be the dominant driving barrier in Kamble et al. (2018); however in this study it does not feature in the most critical barriers. For CSC barriers, the results of Mangla et al. (2018) showed that “lack of environmental laws and regulations” and “lack of preferential tax policies for promoting the circular models” are the key barriers, showing a different perspective to this study. Differences in these results may be caused by the research environment. In this paper, focusing on synchronized barriers by combining Industry 3.5/ Industry 4.0 and CSC barriers is the key theoretical contribution to enriching current literature.

6. Conclusion

New industrial revolutions, so called Industry 4.0 and circular economy, are two major trends in worldwide manufacturing. Organizations need to follow digital transformation and circularity requirements to stay competitive and to achieve more sustainable resource management. This ensures gaining environmental, social and economic advantages. Industry 4.0 transition, so called Industry 3.5, is a hybrid strategy for a technological transition; it supports managing sustainable resource management where similar principles within a circular economy is followed. However, these two transitions are challenging for organizations. In this study transition to Industry 4.0 is defined as Industry 3.5.

This study especially focuses on CSC context in the Industry 4.0 environment with a core of transition barriers. Both Industry 4.0 transition, in other words Industry 3.5, and circularity transition require great effort. In the current business environment, organizations need to deal with these barriers simultaneously for more sustainable resource management. From this point of view, this study differentiates from previous literature which has focused on Industry 4.0 barriers and CSC barriers separately, by presenting synchronized barriers. Two research questions are asked in this study - “What are the CSC barriers to Industry 3.5/Industry 4.0?” and “What are the priorities of these barriers that management should address?”

In order to answer the first research question, 13 synchronized barriers for CSCs in Industry 4.0, derived from a literature review and focus group discussions, are presented. For the second research question, fuzzy ANP method is used for prioritization of the barriers to guide policymakers through the circularity and Industry 4.0 transition.

Results of the study show that lack of knowledge about data management, lack of understanding of decentralized organizational structure for supplier collaborations and high investments in Industry 4.0 technologies and circular approaches are the most important barriers that organizations should initially tackle.

The main limitation of this work is that the current study is based on Industry 3.5, in other words, transition to Industry 4.0. Therefore, as time passes and the adaptation to Industry 4.0 filters through organizations, these synchronized CSC barriers may change and the rank of priority may vary. Future studies may focus on the potential solutions for CSC and Industry 4.0 barriers. The cause and effect relations among the proposed set of barriers can be scrutinized. Another field for future research is data sharing and security; for example the integration of Blockchain technologies to overcome the proposed barriers can be examined. In addition to that, the changing human resource features, such as competencies and skills, can lead to another field of research.

CRediT authorship contribution statement

Yesim Deniz Ozkan-Ozen: Writing - original draft, Methodology, Formal analysis, Resources, Investigation, Conceptualization, Visualization. **Yigit Kazancoglu:** Project administration, Conceptualization, Investigation, Supervision, Writing - original draft. **Sachin Kumar Mangla:** Resources, Supervision, Writing - review & editing.

Declaration of Competing Interest

None.

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