YAŞAR UNIVERSITY
GRADUATE SCHOOL

MASTER THESIS

ANALYZING THE BARRIERS TO SERVITIZATION WITH THE INDUSTRY 4.0 PERSPECTIVE

TİLBE ADSIZ

THESIS ADVISOR: ASSOC. PROF. YÜCEL ÖZTÜRKOĞLU

LOGISTICS MANAGEMENT PROGRAMME

PRESENTATION DATE: 09.04.2021

BORNOVA / İZMİR
MAY, 2021

ABSTRACT

ANALYZING THE BARRIERS TO SERVITIZATION WITH THE INDUSTRY 4.0 PERSPECTIVE

Adsız, Tilbe
MA Thesis / Logistics Management
Advisor: Assoc. Prof. Yücel Öztürkoğlu
May 2021

Servitization is seen as a means of competition among companies and aims to provide value by adding services to products. We aim to bring a different perspective to the concept of servitization, which has been addressed by many researchers since the 1980s. For this reason, we will focus on industry 4.0, which plays a significant role in our lives with the developing technology. Industry 4.0, which was first introduced at the Hannover Fair in 2011, is defined as the transition to smart systems, bringing a new understanding to the production and service sectors. Companies that want to adapt to developing technological applications are faced with some barriers. This study aims to analyze the importance of these barriers for companies. The 12 critical barriers obtained from the literature review were directed to 7 experts working in different companies. Fuzzy linguistic variables were used to convert verbal expressions into numerical expressions in line with the obtained answers. Also, Fuzzy DEMATEL was chosen the most suitable method for our study.

Key Words: Servitization, Industry 4.0, DEMATEL, Fuzzy DEMATEL, Barriers

ÖZ

ENDÜSTRİ 4.0 PERSPEKTİFİ İLE HİZMETLEŞTİRME ÖNÜNDEKİ ENGELLERİ ANALİZ ETMEK

Adsız, Tilbe
Yüksek Lisans Tezi, Lojistik Yönetimi
Danışman: Doç. Dr. Yücel Öztürkoğlu
Mayıs 2021

Hizmetleştirme, şirketler arasında bir rekabet aracı olarak görülmekte ve ürünlere hizmet katarak değer sağlamayı amaçlamaktadır. 1980'lerden bu yana pek çok araştırmacı tarafından ele alınan hizmetleştirme kavramına farklı bir bakış açısı getirmeyi amaçlıyoruz. Bu nedenle gelişen teknoloji ile hayatımızda önemli rol oynayan endüstri 4.0'a odaklanacağız. İlk olarak 2011 yılında Hannover Fuarı'nda tanıtılan Endüstri 4.0, üretim ve hizmet sektörlerine yeni bir anlayış getiren akıllı sistemlere geçiş olarak tanımlanıyor. Gelişen teknolojik uygulamalara uyum sağlamak isteyen şirketler bazı engellerle karşılaşmaktadır. Bu çalışma, bu engellerin şirketler için önemini incelemeyi amaçlamaktadır. Literatür taramasından elde edilen 12 kritik engel, farklı şirketlerde çalışan 7 uzmana yönlendirildi. Elde edilen cevaplar doğrultusunda sözel ifadeleri sayısal ifadelere dönüştürmek için bulanık dil değişkenleri kullanılmıştır. Ayrıca, Bulanık DEMATEL çalışmamız için en uygun yöntem seçilmiştir.

Anahtar Kelimeler: Hizmetleştirme, Endüstri 4.0, DEMATEL, Bulanık DEMATEL, Engeller

ACKNOWLEDGEMENTS

First of all, I would like to thank my advisor Assoc. Prof. Yücel Öztürkoğlu for her guidance and patience during this study.

I would like to express my enduring love to my family, who are always supportive, loving and caring to me in every possible way in my life.

Tilbe Adsız

İzmir, 2021

TEXT OF OATH

I declare and honestly confirm that my study, titled “ANALYSIS THE BARRIERS OF THE SERVITIZATION WITH INDUSTY 4.0 PERSPECTIVE” and presented as a Master’s thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Tilbe Adsız
April, 2021

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

PSS Product Service System

GE General Electric

IBM International Business Machine

BRIC Brazil, Russia, India, and China

CPSS Cyber-Physical Production Systems

ICT Information and Communication Technology

IoT Internet of Things

OHS Occupational Health and Safety

UK United Kingdom

DEMATEL Decision-making trial and evaluation laboratory

CHAPTER 1
CONCEPTS OF THE SERVITIZATION

1.1 History of the Servitization

Manufacturing companies have been companies that continued to serve during their existence. Considering the literature, it has been observed that the companies providing services are generally industrial companies. However, this situation has changed over time and today most companies have started to be interested in the service sector (Vandermerwe & Rada, 1988). The pressure on manufacturing industries has forced companies to differentiate and innovate. Especially in countries with developed economies, many manufacturing companies have made changes in their products by offering additional services (Silva et al., 2018). Vandermerwe and Rada see services as a means of competition on a global scale among companies and have adopted the view that such companies can create value by blending their strategies with services (Kowalkowski et al., 2017). Generally, the term "servitization" is used in the literature for this concept, briefly which means creating value by adding services to products (Baines et al., 2009; Dinges et al., 2015). The Figure 1.1. below summarizes the concept of servitization.

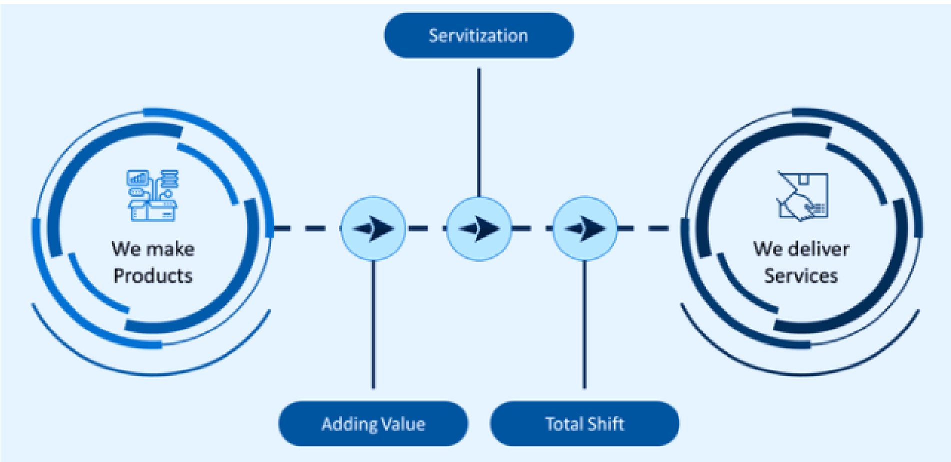

Figure 1.1. The Concept of Servitization

Source: (Servitization, 2020)

This transition from product to service-oriented business models in manufacturing industries has played a significant role in determining the strategies of manufacturers. This transition has been researched and conceptualized in different ways by many scientists since the 1980s. (Paiola & Gebauer, 2020). Different terms have been used for this concept. The most common ones are servitization (Vandermerwe & Rada, 1988; Baines et al., 2009; Neely, 2009), product-service system (PSS) (Mont, 2002; Tukker, 2004).

Some studies consider the terms PSS and servitization synonymous, but there are differences between the two terms (Beuren et al., 2013). While the transformation of product-oriented business models into service-oriented business models is called ‘’servitization’’ (Kowalkowski et al., 2017), PSS refers to the system in which the buyer no longer buys the product but only purchases the output of the product (Tukker, 2004). According to Baines et al. (2007), PSS is expressed as a special servitization case. While the focus of servitization has been on customer needs and meeting these needs through core business activities, the focus has changed over time. The focus has shifted to establishing and maintaining relationships between broader offerings and companies and their customer bases (Vandermerwe & Rada, 1988).

Over time, the concept of servitization has been defined in different ways by many authors. Vandermerwe and Rada (1988) was the first to define the concept of the "servitization" that occurs in almost every sector on a global scale. Companies tend to sell knowledge and create expert services in addition to the products they produce. Vandermerwe and Rada see services as a means of competition on a global scale among companies and have adopted the view that such companies can create value by blending their strategies with services (Kowalkowski et al., 2017). Also, Vandermerwe and Rada (1988) argued that the business goes through three different phases until it reaches the servitization phases. A summary of these three phases is shown below (see Figure 1.2).

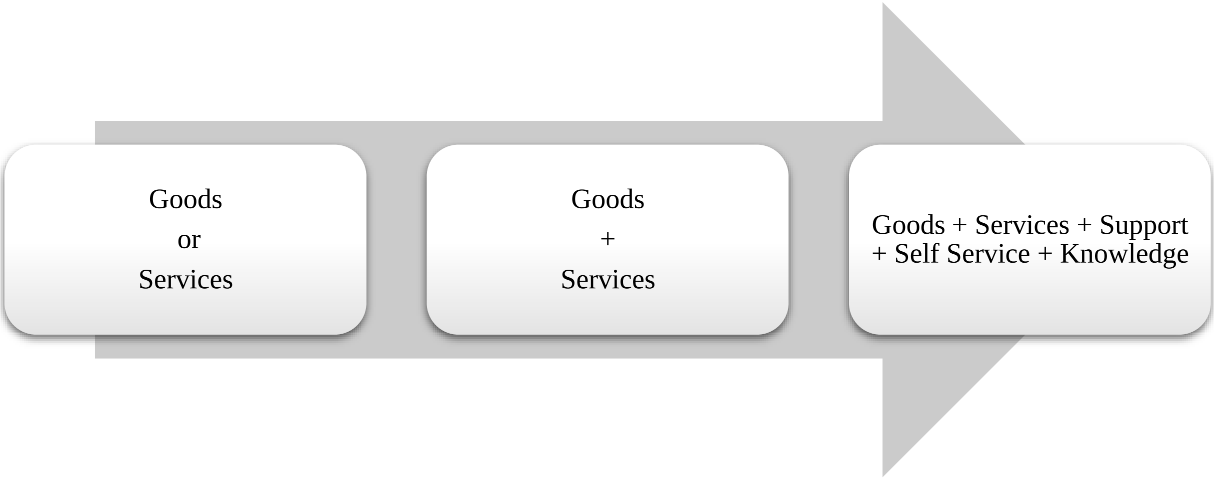

Figure 1.2. Servitization Phases

Source: Vandermerwe & Rada (1988)

I. *Goods or Services:* In the first phase, companies produce only one of the goods or services.
II. *Goods + Services:* With the opportunities provided by the developing technology and the emergence of new trends, companies have started to produce both goods and services.
III. *Goods + Services + Support + Self Service + Knowledge:* In the last phase, services are presented to customers in bundles. These bundles consist of customer-oriented combinations of goods, services, support, self service, and knowledge.

Baines et al. (2007) and Neely (2009) defines servitization as the innovation of an organization's capabilities and processes and emphasizes the transition from product sales to sales of PSS. Thus, mutual value creation is provided. Silva et al. (2018) defined servitization as a new reality that enables them to find the approach necessary to be competitive in the sector despite the changes in the existing working methods. In other words, servitization is a change of mind in adapting the business models of organizations to integrated systems with a "pure product" perspective (Rudnick et al., 2020). Servitization provides many benefits to companies, consumers, and society. For example, (Dinges et al., 2015)

a) Service providers earn increased revenues and margins, thus reducing competition.
b) Customers can maximize equipment performance.

c) It is ensured that consumers receive better products and services, and it can meet their needs completely.
d) It provides sustainability and environmental performance to society.

Warranties, maintenance, and revenue usage agreements can be shown as an example of the services offered with the product (Ennis et al., 2020). Baines and Lightfoot (2013) based these examples on a classification. According to this classification, warranty is base, maintenance intermediate, and contract is an example of advanced service.

Major manufacturers such as Rolls-Royce, General Electric (GE), and KONE have advocated that companies' services should be integrated with their offerings. In this way, they thought they would benefit more. They also saw servitization as a gold mine for manufacturing companies (Huikkola et al., 2016). Another company that applies servitization is "International Business Machine (IBM) Corporation", which is a multinational technology company (Ahamed et al., 2013).

1.2 Literature Review: Servitization

The authors have conducted many studies to draw attention to the importance of the concept of servitization in the sector. Table 1.1 shows the most important studies about servitization during time period of 2011-2020.

Table 1.1. Literature Review of the Servitization (2011-2020)

Year	Author(s)	Purpose of the Study
2011	Lin et al.	To determine the strategies of servitization in China computer industry and making recommendations to policymakers and industry.
	Neely et al.	To examine the changing situation of the services provided by companies in the manufacturing sector over time.
	Tether & Bascavusoglu-Moreau	To research the services provided by manufacturing companies in the United Kingdom (UK) for their customers, examining the results of service provision and the necessary motivation.

2012	Lertsakthanakun et al.	To examine the suitability of companies to servitization and developing a framework with relevant factors.
	Turunen & Neely	To determine the servitization strategies required by the companies, creating a framework with the different organizational designs realized in this direction.
	Visnjic & Van Looy	To examine the impact of service innovations on the performance of manufacturing companies and suggesting ways to achieve sustainable growth.
2013	Ahamed et al.	Improving the transition from pure production to servitization and determine the factors for the implementation of servitization strategies.
	Lightfoot et al.	To examine the contribution of research communities dealing with servitization to knowledge production.
	Neely	To explain the state of servitization in Germany and to make a comparison between some countries.
2014	Crozet & Milet	To examine the changes in French manufacturing companies have experienced in service production over time.
	Smith et al.	To examine operations management and emerging PSS proposals in the transition to servitization.
	Turunen & Finne	To examine the effects of production activities carried out in different organizational environments on the servitization.
2015	Bustinza et al.	To examine the transition of 102 multinational company managers to basic, medium, and advanced services.
	Li et al.	To examine the state of servitization and the impact of the servitization on the business performance of manufacturers in the Zhejiang Province of China.

	Opresnik & Taisch	To assist manufacturing companies in the Manufacturing Service Ecosystem (MSE) for the servitization.
2016	Calabretta et al.	To provide a design approach to the tools and applications used by companies that transition to service innovation.
	Ha et al.	To examine the productivity of Korean manufacturing SMEs, and in this direction comparing servitized and non-servitized companies.
	Pal	To investigate how companies in the used clothing industry expand their responsibilities by providing services at PSS.
2017	Ayala et al.	To explain how manufacturing companies aiming for a service-based business model integrate information from service suppliers.
	Kowalkowski et al.	To suggest definitions for four basic terms (servitization, service infusion, deservitization and service dilution).
	Rabetino et al.	To develop an understanding of the servitization application.
2018	Rabetino et al.	To examine the studies on servitization and to reveal the developments that will affect the future
	Wang et al.	Performing a quantitative review of the relationship between servitization and performance.
	Ziaee Bigdeli et al.	To examine the transformation of manufacturers to advanced service providers and evaluate the results.
2019	Calabrese et al.	Contributing to the servitization literature
	Doni et al.	To examine the potential impact of servitization on sustainability, with a study of 208 manufacturing companies located in Europe.

	Raddats et al.	To review the literature of servitization based on four main streams between 2015-2017.
2020	Baines et al.	To define the servitization process and organizational changes and investigating the causes that affect these processes. Then, to develop a model in this direction.
	Rudnick et al.	To develop a lean servitization canvas
	Wang et al.	To make a detailed examination of servitization in operations management in the ICT era, which is a new era.

Source: Author

It has been observed that there is an increasing interest in service-oriented strategies in manufacturing companies. Companies that want to increase their performance and gain competitive advantage have turned to servitization and make it possible for customer satisfaction and differentiation (Bustinza et al., 2015).

Wanting to increase profits and add value to their products, Chinese computer manufacturers have turned to servitization. Lin et al. (2011), who conducted a case study in this direction, they have defined two types of servicing strategies, product-centered and service-centered. Thus, it offered options to Chinese computer manufacturers. Li et al. (2015), on the other hand, analyzed 134 companies in Zhejiang, China, in 2012. In this analysis, they observed a positive relationship between job performance and service provision. They also noted that servitization is generally more suitable for big companies and that the performance impact thus reaches remarkable. Another study that draws attention to the relationship between servitization and performance, it was carried out by Wang et al. (2018). In this study, it was determined that the relationship between these two concepts was affected by the operational structure and control variables.

To contribute to the value creation processes of product-service companies, Visnjic, and Van Looy (2012) carried out a study involving the manufacturer company called Atlas Copco Compressor Technique between 2001 and 2007. In addition to providing information about how the company can achieve revenue growth and profitability, it has also shown that there is a positive relationship between servitization and profitability. Ahamed et al. (2013) discussed the transformation of IBM Corporation, which is a manufacturing company, from a product-centered structure to a service-oriented structure. Smith et al. (2014), on the other hand, conducted a study that helped future producers to compete in service economies.

Neely conducted a study in 2009 to reveal the results of the financial impact of servitization on production and then updated this study and made another study in 2011. The article conducted by Neely et al. (2011) used the OSIRIS database in this study. This study investigates the changing situation of the services rendered by companies in the manufacturing sector and covers three different periods (2007-2009-2011). It shows that in 2007, 58% of the US producers provided services, while less than 1% of the Chinese producers. In 2011, this situation changed and dropped to 55% in the USA and rose to less than 20% in China.

While Tether and Başçavuşoğlu-Moreau (2011) examined the servitization situation of production companies in the UK, Neely (2013) explains the state of servitization in Germany and makes a comparison between some countries. This study comparing the servitization levels of selected countries also provides information about the international developments experienced. According to this research, it has been concluded that the level of servitization in Germany is higher than BRIC (Brazil, Russia, India, and China) countries, but lower than countries such as the USA and the UK. The rate of servitization in the USA is 30.64%, followed by the UK with 28.44%. Other countries with servitization rates are Germany 25.34%, India 24.22%, Russia 19.23%, France 18.01%, China 14.30%, Brazil 10.94%. CapitalIQ database was used for this study and data of approximately 42,000 companies were included for analysis. In Crozet and Milet's (2014) article about the manufacturing companies in France between 1997 and 2007, attention was drawn to servitization. They stated that about 83% of French manufacturing companies sell services, while one-third of them sell services rather than products.

Lertsakthanakun et al. (2012) conducted interviews and case studies with four Thai companies. In this direction, a framework was created by determining the factors to make servitization sustainable. This framework allows companies to assess the appropriateness of servitization. Manufacturers who want to increase their service provision need structural changes. Turunen and Neely (2012), which examines the changes that occur in the transition to service provision, describe the stages of servitization. Ziaee Bigdelia et al. (2018) article, on the other hand, determine the progress of manufacturing companies in becoming an advanced service provider and the results achieved.

Moreover, Turunen & Finne (2014), Calabretta et al. (2016), Calabrese et al. (2019), and Raddats et al. (2019) carried out their study to contribute to the literature on servitization. Many unexpected factors affect the servitization of industrial manufacturers. Turunen and Finne (2014) help managerial decision-making processes related to servitization, as well as contributes to the literature on the transition towards service delivery. They also aimed to present some propositions for these affected organizational environments. Calabretta et al. (2016) aim to propose a design approach to be used in service innovation and efficient applications. Calabrese et al. (2019) focused on the measurement of servitization levels in companies. Although this study is an example of a systematic literature review, it is the first study that developed into the operationalization and conceptualization of the measurement of servitization levels. Raddats et al. (2019) brought a perspective to the service literature on specific topics such as general management, marketing, operations, and service management between 2015-2017. Similar issues were discussed in the study conducted by Baines et al. (2020). This study creates a model by explaining the processes of servitization, organizational changes, and the factors that affect the processes. It also includes 14 case studies, which makes it easier to understand the process and proposes a model.

Research communities have various contributions in knowledge generation, and these communities, which have dealt with the concept of servitization, have conducted studies to identify these contributions. Lightfoot et al. (2013) focused on two main issues in their article; While determining the location of the information stocks and flows among these communities, it is also to raise the concerns these communities have in the research.

Manufacturing companies are implementing some strategies to servitization. Wanting to develop an understanding of servitization practices, Rabetino et al. (2017) carried out a comprehensive review of the concept of servitization. This study enables manufacturing companies to plan and implement effective strategic plans. Also, Rabetino et al. (2018) discussed the concept of servitization in the other study and tried to link these studies accepted by scientific communities by organizing them. This study showing structure of the servitization area, at the same time, draws attention to the change in different theories, concepts, and methods used. For nearly 50 years, strategies such as service expansion and service reduction have been implemented in many sectors. Kowalkowski et al. (2017) focused on four main concepts (servitization, deservitization, service infusion, and service dilution) and tried to clarify these concepts.

The opportunities created by big data and servitization provide competitive advantages to manufacturing companies. For example, Opresnik and Taisch (2015) drew attention to the impact of using "Big data" to assist manufacturing companies within MSE in servitization. While this strategy makes it possible to create a new product or service, it creates new revenue streams and enables producers to improve themselves.

Companies often that implement the servitization strategy encounter difficulties brought by a lack of knowledge in production activities. Therefore, they aim for the innovation of the service-based business model and seek ways to obtain this information from service suppliers. Ayala et al. (2017) conducted a study to indicate how this information is integrated into processes.

Doni et al. (2019) identified two groups (pure manufacturers and nonpure manufacturers) using job descriptions in the Bloomberg database. For this study, 208 companies were investigated in Europe. In this study, it has been observed that environmental performance increases, and energy consumption improves with servitization.

According to Pal (2016), companies in the used clothing industry have expanded their responsibilities through service delivery. Accordingly, it included PSS practices and concluded that this situation also requires some corporate responsibilities.

Rudnick et al. (2020) developed a lean servitization canvas by conducting a literature study on lean servitization. The lean servitization canvas adds value to after-sales processes and, at the same time enables the combination of physical and digital flows. They also confirmed this study by doing a case study. Companies of ‘‘NedTrain in the Netherlands’’ and ‘‘Siemens in Germany’’ were evaluated and compared, the main activities of both companies are infrastructure and transportation. Thus, the focus of the research is high capital goods in the rail and infrastructure sectors. This research highlighted the importance of digitalization to provide superior services in the aftermarket. The primary objectives of the companies have been to provide additional revenue streams. Also, they tried to make the users' experiences valuable by providing reliable and fast maintenance programs.

Manufacturing companies need innovation to compete. The development of technology has created a competitive environment, especially for companies in the manufacturing industry. For instance, SMEs in Korea have recognized that product and service integration has a significant impact. Moreover, servitization has enabled Korean manufacturing SMEs to develop efficiently (Ha et al., 2016).

Increasing technological developments in recent years have created a new era of ICT. This ICT era, on the other hand, has become the subject of discussion with the integration of servitization applied in operations management with technological developments. Wang et al. (2020) addressed these issues in their study. In the next section will be discussed the concept of digital servitization that emerges with the impact of technology.

CHAPTER 2
DIGITAL SERVITIZATION

2.1 History of the Digital Servitization

Technology has played a significant role in changing consumption patterns and lifestyles (De Propris, 2016), product service integration, service development and service delivery (Dinges et al., 2015). In addition to enabling companies to create real-time services, it has also helped improve consumers' knowledge of products and services. While this situation shows the companies' need for technology, it also revealed the convenience it provides to companies in information exchange (Vandermerwe & Rada, 1988).

The use of digital technologies to create new value, generate revenue, and change existing business models has been named "digitalization" (Gartner Glossary, 2020). Traditionally, digitalization is defined as the process of creating an effective and efficient economic value using computer and internet technology (Reddy & Reinartz, 2017). The concept of "digitization" is sometimes used instead of this term (Visonà, 2020). Technological developments have a great impact on the field of manufacturing, and automation of production processes has been allowed with digitalization (Ennis et al., 2020). Also, researches have drawn attention to the importance of digitalization in strategy development in the service sector. While digitalization helps to support global service innovation (Parida et al., 2015), it also has an impact on all business models (Luz Martín-Peña et al., 2018).

Kindström and Kowalkowski (2014) determined that using digital technological systems (for example, an adaptive back-office infrastructure with smart information and communication technology (ICT) systems) provides the development of low-cost operations, and they also offer high service quality. They also stated in their study that with the formation of such an infrastructure, better resource allocation would be made, and it would facilitate correct information sharing within the field.

Figure 2.1. Integration of Servitization and Digitalization

Source: Author

Companies have seen the integration of servitization and digitalization concepts as a competitive advantage to create value (Silva et al., 2018). Figure 2.1 shows the integration of the servitization and digitalization. Especially in recent years, many authors have carried out studies drawing attention to the relationship between these servitization and digitalization (Paschou et al., 2017; Vendrell-Herrero et al., 2017; Luz Martín-Peña et al., 2018; Marjanovic et al., 2019; Abou-foul et al., 2020; Gebauer et al., 2020; Kharlamov & Parry, 2020; Kohtamäki et al., 2020). Vendrell-Herrero et al., (2017) defined digital servicing as 'the provision of digital servitization embedded in physical products'.

According to Kohtamäki et al. (2019), digital servitization is the transition to smart product-service-software systems that provide value creation with monitoring, control, optimization, and autonomous functions. They also argued that for companies to gain value by offering digital servitization, they should benefit from three dimensions of digital offerings. These three dimensions are product, service, and software.

Digital servitization is characterized by long-term commitment, co-creation, and investment in relationships, thus aiming to build closer provider-customer relationships. Engaging in close collaborative relationships provides operational efficiency while at the same time facilitating the achievement of customer goals (Kamalaldin et al., 2020). Also, manufacturing companies that want to improve their financial performance need to invest in digital servitization (Kohtamäki et al., 2020).

2.2 Literature Review: Digital Servitization

Digital servitization is defined as the process of transition from pure products and additional services to smart PSS (Kohtamäki et al., 2020). Digital servitization has been an important issue that authors have included in their studies, especially in recent years. Some examples of these studies are shown below (see Table 2.1).

Table 2.1. Literature Review of the Digital Servitization (2016-2020)

Year	*Author(s)*	*Purpose of the Study*
2016	Ardolino et al.	Examining the impact of digital technologies on servitization in manufacturing companies.
2017	Paschou et al.	To obtain scientific information about digital servitization and to systematize this information.
2018	Luz Martín-Peña et al.	To conduct a systematic literature review on servitization and digitalization
2019	Marjanovic et al.	Examining the impact of the digital servitization portfolio on firm performance
2020	Abou-foul et al.	To develop a framework to examine the impact of servitization and digitalization on the financial performance of manufacturing companies.
2020	Gebauer et al.	To examine the main aspects of the digital servitization debate and highlight the growth paths of companies with case studies.

Source: Author

Ardolino et al. (2016) focused on seeking answers to two research questions.

1) With the development of digital technologies, which capabilities are essential for providing product-service solutions?
2) How does the emergence of technologies such as cloud computing, predictive analytics, and IoT affect the servitization practices of manufacturing companies?

A literature review was conducted to find answers to these research questions. In this direction, eleven digital capabilities (Identification (user), Identification (product), Geo-localisation, Timing assessment, Intensity assessment, Condition monitoring, Usage monitoring, Prediction, Adaptive (remote) control, Optimization, Autonomy) set to provide different product-service solutions and to create efficient service delivery practices.

Paschou et al. (2017) argued that the combination of servitization and digital technologies created opportunities in production. They stated that their studies on digital servitization were insufficient. They examined the importance of digital technologies in the services provided in the field of production by drawing a systematic literature framework. These reviews have shown that the issue of digital servitization is a new topic. It is a topic that has increased in importance in recent years in the academic field in recent years and has been addressed by many authors. This study is a significant example of a literature review that may be useful for future studies.

Servitization is a process that supports digitalization, and there is a strong bond between them. Also, these two concepts have a mutual influence on business models and create new digital business models (DBM). Luz Martín - Peña et al. (2018) explains the relationship between the concepts of servitization and digitalization in their study.

The role of digital technologies in production has been one of the neglected issues. Marjanovic et al. (2019) conducted a study to draw attention to the effect digital servitization has on the performance of companies. In the study, the Serbian datasets used by 240 manufacturing companies, which were the subject of the European Manufacturing research conducted in 2018, were used. This study demonstrates the positive impact of digital servitization on companies' turnover levels. Company executives should implement strategies such as web-based services for customized product design and web-based offers for product use. Most importantly, managers should provide digital services according to their industry type. Thus, the company will have the chance to maximize their performance.

According to studies of Abou-foul et al. (2020), one of the main goals of manufacturing companies is to provide companies with profitability and growth opportunity through the integration of servitization and digitalization. This study covers 185 European and US manufacturing companies. These companies are those that show that digital servitization directly affects financial performance. This study has shown that the combination of servitization and digitalization speeds up the transition process of manufacturing companies to service provision. In addition, companies should adapt the physical and technological aspects offered in the market to their companies in order to get efficiency from these processes.

Gebauer et al. (2020) stated in their study that many product companies now choose the ways of servitization, and recently this situation has shifted towards digital servitization. With a case study covering six companies (*IBM*, Cisco, Apple, GE, *Voith Group, and Intel),* they highlighted the importance and place of digital servitization. IBM is one of the most prominent examples of the transition from product-oriented systems to service-oriented systems and has recently been a pioneer in digital growth. It generates approximately 39% of its revenue from digital products. Cisco, on the other hand, is a company that always provides value for its customers and has financial flexibility. Cisco provided 75.1% of its total revenue from products and 24.9% from services in 2019. Apple, one of the leading companies in digitalization, earned 46.3 billion USD from digital services in 2019. GE, one of the pioneers of the servitization system, drew attention to the importance of digitalization to seek new growth in 2015. Voith launched digital initiatives in 2016 to facilitate digital growth. They thought that the company applying digitalization would increase its value and provide additional revenue streams. Intel, a product company, started a transformation and increased its revenue. It offers various digital solutions for its customers.

The concepts of servitization and digital servitization are a topic that has been studied a lot by the authors. However, there is still a large gap in the literature about these topics. Our aim in this study is to integrate the concept of servitization with the Industry 4.0 perspective. Then, it is to identify the challenges and barriers in front of servitization achieved with the literature review. Among these identified challenges and barriers, we will choose the appropriate ones for us to study. We will analyze the relationship between the criteria we have determined in this study with the Fuzzy DEMATEL (Decision-making trial and evaluation laboratory) method. Although there are similar studies in the literature, there is no study analyzing the relationship between the barriers encountered. The next section will discussed the integration of servitization with industry 4.0.

CHAPTER 3
INTEGRATION OF THE SERVITIZATION WITH INDUSTRY 4.0

3.1 History of the Industrial Revolution

The first industrial revolution started with water and steam-powered mechanical manufacturing in 1784 (Davies, 2015). This period has been recognized as the beginning of a new age and the most radical innovation in human history (Visonà, 2020). With the industrial revolution, the transformation of manual work into the first manufacturing processes took place, especially in the textile industry. This period has also improved the quality of life and has been the main driver of change (Rojko, 2017).

Mass production began with the development of electrical and assembly lines towards the end of the 19th century. This situation is the most important factor that started the second industrial revolution (Davies, 2015). Another name for the second industrial revolution is the standard production era (Visonà, 2020).

The third industrial revolution, also known as the beginning of the information age, started in the late 1960s (Visonà, 2020). In this period, automatic systems were developed with the help of information technology and electronics (Schwab, 2016).

The fourth industrial revolution, which is the period we are in, is being built over the third industrial revolution. As in every industrial revolution, there are potential benefits such as improving the quality of life and increasing income levels in this period as well. At the same time, technology has brought many benefits. One of its most important features is that it enables new products and services (Schwab, 2016).

When looking at the first three industrial revolutions, three technological changes stand out. These are respectively; the emergence of steam power, electrification, ICTs (Culot et al., 2019).

Figure 3.1. summarizes the transformation process of industrial revolutions over the years.

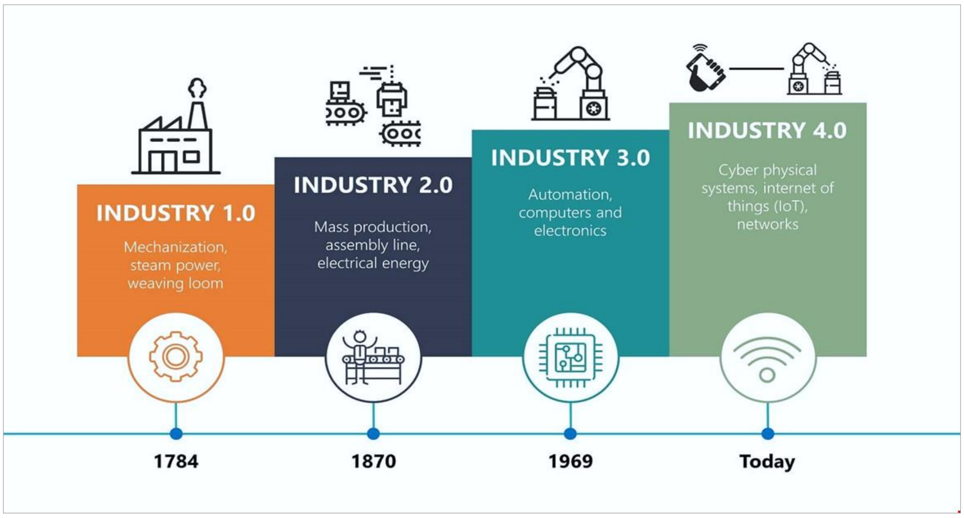

Figure 3.1. Stages of the Industrial Revolution

Source: ("Industry 4.0 Ready", 2020)

3.2 Industry 4.0

Throughout the history of humanity, many developments have taken place, and new technological applications are at the top of these developments. Industrial systems evolution is in constant motion and has led to some changes (Visonà, 2020). Technological developments have always been a factor affecting production (Ennis et al., 2020), and since the beginning of the industrial revolution has increased industrial productivity (Rüßmann et al., 2015). Steam power was used first and then electrical energy to provide the mechanization. The intensive use of electrical energy has made mass production possible. The last process following these developments is the widespread use of digitalization, which has enabled the automation of production processes (Ennis et al., 2020).

The concept of Industry 4.0 was first introduced at the Hannover Fair in 2011 (Ghobakhloo, 2018) by the German Industry-Science Research Alliance. In short, it is also expressed as the digitalization of industrial production (Buhr, 2015). Instead of Industry 4.0 concept, it was used by the authors in concepts such as smart manufacturing, the fourth industrial revolution, and digital transformation. While this concept encompasses the digital transformation processes of traditional industries, it also creates a new production paradigm. As the name suggests, Industry 4.0 is the fourth stage of industrial production. (Culot et al., 2020), and significant leaps in manufacturing took place during this period. It has also been observed around the world to change people's lives and become the successor of the third industrial revolution (Davies, 2015).

According to Germany's Federal Ministry of Education and Research, Industry 4.0 is an increasing the flexibility existing in value-creating networks through the implementation of cyber-physical production systems (CPPS) (Shrouf et al., 2014). Industry 4.0, which has attracted attention from both manufacturers and service companies, includes the combination of supply chain, production facilities, and service systems. This situation provides the formation of value-added networks (Ustundag & Cevikcan, 2017).

Companies are experiencing a new digital era in the industrial world that changes over time. In this digital era, servitization strategies become the driving force of the economy, along with technology (Visonà, 2020). The world is getting more and more digital. The intensive use of the internet has caused companies to resort to new ways to meet customer needs. In addition to influencing people's decision-making processes, this new digital era has also caused some changes in consumer habits (Hudson et al., 2012). Also, the development of technology has made it possible to differentiate, so companies tend to offer personalized services. The service sector has expanded, and the importance of this sector has increased. Also, the quality of service provided has increased, and customer relations have deepened (Rust & Huang, 2014).

While it also enables companies to move away from their traditional approaches, it offers new possibilities in production planning and control (Moeuf et al., 2018). Technologies developed in this period have had a critical impact on the management understanding and organization processes of companies. Many companies have focused on meeting the expectations of their customers by investing in new technologies (Silva et al., 2018).

This period is also known as the rise of new digital industrial technologies and is supported by nine technological advances (see Figure 3.2). These technologies are the building blocks of Industry 4.0 (Rüßmann et al., 2015).

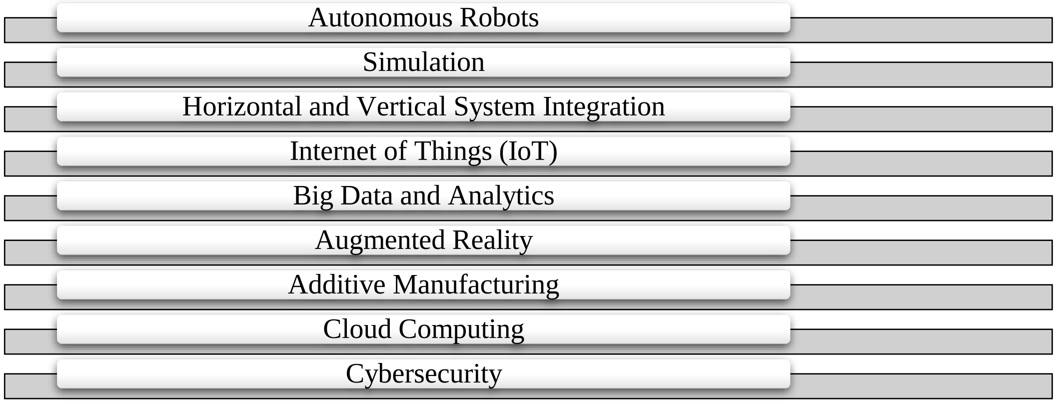

Figure 3.2. Nine Technological Advances

Source: ("Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries", 2015)

According to Davies (2015), Industry 4.0 is based on the technological developments shown below.

- **ICT:** To digitize and integrate information at all product stages, including logistics and supply chain processes.
- **Cyber-physical systems (CPS):** Implementation of ICTs to monitor and control systems or processes. Embedded sensors and smart robots can be given as examples.
- **Network communications:** The system that connects products, systems, machines and people with the production facility, and suppliers through IoT.
- **Simulation:** Applications used to set up production processes and design products.
- Collecting and analyzing large amounts of data through **cloud computing or big data** analysis.
- Providing ICT-based support for employees with **robots and smart tools.**

3.3 The Servitization with Industry 4.0 Perspective

In recent years, in parallel with the development of servitization, manufacturing companies have tried to make their production processes smart. In this direction, they aimed to increase their productivity and efficiency with new technology (Cimini et al., 2018). Moreover, companies have tended to speed up delivery times and create efficient and automated processes, mainly due to the increasing demand for high quality and customized products. This situation has forced companies to adapt to a new era known as Industry 4.0 (Zheng et al., 2020).

Industry 4.0 plays a significant role in the success of a serviced business (Chiarini et al., 2020). Adopting technologies to help support the servitization will create new business models and opportunities for companies (Cimini et al., 2018). In addition to providing new opportunities for manufacturing companies, the digital technologies to be used will have many reflections on the main processes (Zheng et al., 2020). Moreover, Industry 4.0 brings flexibility, adaptation and customization to production and operating models. In addition, the authors think that these developments will strengthen the concept of servitization (Ennis et al., 2020). However, these technologies do not always create an increase in servitization and do not affect the strategies of companies. Therefore, companies need to adapt the right Industry 4.0 technologies to them (Bortoluzzi et al. 2020).

Industry 4.0 and servitization are two concepts that support each other and, so they have to be designed together. While Industry 4.0 focuses on the production of the product with an efficient operational structure, servitization focuses on the effective consumption of the customer. One of the significant examples of Industry 4.0 and servitization relationship is the white goods manufacturer Whirlpool company (Ramachandran & Masood, 2019).

There are some important points to be considered in the integration of servitization and Industry 4.0 (Iyer, 2019).

(i) A tighter Product Lifecycle Management (PLM) process with integrated data management,

(ii) Intelligent management processes, service operations that provide newer business models,

(iii) Effective change management for people, processes, and technology.

In the design and manufacturing industry in the UK, Huxtable, and Schaefer (2016) focused on how industry 4.0 applications will affect servitization. Besides, this study includes the kinds of services that arise as a result of Industry 4.0 applications and SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of the impact of Industry 4.0 on servitization. In this direction, they analyzed 57 companies in the UK.

As a result, it was determined that 61% of these companies offered product-service integration, and 39% only earned income from product sales. Huxtable and Schaefer (2016) stated the SWOT analysis they reached with the literature review in their study. Companies often pay attention to these issues before integrating Industry 4.0 related services into their business strategies (see Figure 3.3).

Figure 3.3 SWOT Analysis of Servitization and Industry 4.0 Integration

Source: Huxtable and Schaefer (2016)

Recently, the concept of servitization and industry 4.0 has been of interest to researchers separately. However, studies conducted by combining these two concepts are scarce in the literature. In other words, few studies on servitization have addressed the Industry 4.0 subjects. The subjects examined are generally limited to the concept of digital transformation (Frank et al., 2019).

The increasing interest in the servitization business model has led companies to implement digital systems in their products and machines. For example, IoT, which enables physical objects to be connected to the internet, enables service providers to improve customer relationships while at the same time differentiating their offerings for their customers (Silva et al., 2018).

Ennis and Barnett (2019) focus on the examination of a mature public transportation system from the perspective of servitization. The aim is to explore collaborative supply networks in the context of industry 4.0. Ennis et al. (2020), on the other hand, focuses on the changing environment of Industry 4.0, taking into account the servitization perspective. They also aimed to develop a new conceptual framework by considering B2B value ecosystems and competitive dynamics.

The study of Frank et al. (2019) builds combinations that create value for both customer and internal processes while highlighting the combination of potential service offerings and digital technologies. Shows the complexity of applying different configurations between servitization and digital technologies. Also, it shows a range of levels of complexity for the implementation of digital and service levels in product delivery, and these levels can help managers through a BMI process.

Torrecilla-García et al. (2019) focuses on Occupational Health and Safety (OHS) strategies from a servitization and Industry 4.0 perspective. The integration of OHS strategies and processes attract the attention of researchers as it will cover different risk prevention requirements.

In the study conducted by Bortoluzzi et al. (2020), for small and medium-sized companies (SMEs) operating within the scope of business-to-business (B2B) focuses on the transition of companies from product-based business models to service-based business models. They thought that such a transition would be accelerated by Industry 4.0 technology, such as simulation, big data collection, IoT, and cloud computing. This study shows the effect of Industry 4.0 technologies on the spread of servitization strategies. At the same time, the results of these effects were discussed in terms of company performance.

Tabaklar and Yildirim (2020) aimed to develop an understanding of servitization realized in the age of Industry 4.0 from the supply chain management perspective. This study reveals that Industry 4.0 has not yet been fully developed during servitization applications.

Industry 4.0 causes several changes in the behavior and strategies of companies, and with these changes, some transformations are experienced in production, operations, and services. Drawing attention to this transformation, Grandinetti et al. (2020) focused on the effects of industry 4.0-based servitization between suppliers and customers in the context of B2B. It is an exploration study involving 22 Italian B2B manufacturing companies.

Visonà (2020) presented two different case studies addressing servitization and industry 4.0. Two manufacturing companies, Sariv and Arneg, were included in this study, and interviews were held with the managers of these companies. First, a detailed study was conducted on the effects of integrating processes with industry 4.0 technologies on companies, and then the strategies and technological applications used by companies were reviewed. According to this study, the digitalization of processes will enable both companies to strengthen their organizational and production capabilities. It will also provide ideas on how companies can succeed in differentiating themselves through their servitization strategies. In these two companies, it has shown that with the help of digital technologies, manufacturing companies can gain a competitive advantage in servitization.

In the literature, Industry 4.0 has been discussed in terms of both servitization and digital servitization. In this context, the studies mentioned above are shown in Table 3.1.

Table 3.1. Literature Review of the Servitization and Digital Servitization from an Industry 4.0 Perspective

Topic	Author(s)
Servitization & Industry 4.0	Huxtable & Schaefer (2016); Ennis & Barnett (2019); Frank et al. (2019); Torrecilla-García et al. (2019); Bortoluzzi et al. (2020); Ennis et al. (2020); Tabaklar & Yildirim (2020)
Digital Servitization & Industry 4.0	Grandinetti et al., (2020); Visonà (2020)

Source: Author

The main aim of this study is to integrate the concepts of servitization and industry 4.0. Companies that adopt this integration face some barriers before and during their implementation. This study also focuses on identifying these barriers and evaluating the relationship between the concepts of servitization and industry 4.0.

As stated above, the authors evaluated the subject from different angles in their studies. In this study, we will analyze for the first time the barriers to servitization from the perspective of industry 4.0 using an analysis method. We will discuss the barriers encountered in the next section.

CHAPTER 4
BARRIERS OF THE SERVITIZATION WITH INDUSTRY 4.0 PERSPECTIVE

The main aim of the study is to identify the barriers and challenges of the servitization with an industry 4.0 perspective. To achieve this aim, firstly, we made a detailed literature review. There are many studies in the literature about the barriers to servitization. However, since our focus in this study is the industry 4.0 perspective, barriers to industry 4.0 applications are also included in our list. We collected a total of 12 barriers from the barrier literature. Table 4 shows the barriers that are suitable for our study among the barriers we obtained from the literature.

The literature review that has been conducted highlights the various barriers and challenges to servitization. For instance, Hou and Neely (2013) conducted a systematic literature review on the barriers to servitization. In this line, they divided the servitization barriers into seven different groups: *(i) Competitors, suppliers & Partners; (ii) Society & Environment; (iii) Customers; (iv) Finance; (v) Knowledge & Information; (vi) Products & Activities, and (vii) Organizational Structure & Culture*.

In our study, inspired by the literature review conducted by Hou and Neely (2013), we divided the barriers into three main groups.

(i) ***Finance,***

(ii) ***Information & Capability,***

(iii) ***Technological***

We conducted a detailed literature review and identified 12 barriers in total. These barriers we have determined are grouped under three main headings and are shown in Table 4.1.

Table 4.1. Barriers to Servitization with Industry 4.0 Perspective

	Barriers	Source(s)
Finance	Lack of financial resources	Caldeira & Ward (2003); Schroeder et al. (2016); Klein et al. (2018); Adams (2019)
	Costs and investments/ High Implementation Cost	Gebauer et al. (2005); Confente et al. (2015); Davies (2015); Kamble et al. (2018); Hussain, (2019); Marcon et al. (2019)
Information & Capability	Insufficient information about customers' needs	Klein et al. (2018); Marcon et al. (2019); Michalik et al. (2019)
	Lack of qualified employees	Brax (2005); Davies (2015); Huxtable & Schaefer (2016); Kamble et al. (2018); Adams (2019); Hussain, (2019)
	Lack of information/ knowledge	Westergren & Jonsson (2004); Confente et al. (2015); Michalik et al. (2019)
	Insufficient collaborations- cooperation / Coordination problems	Martinez et al. (2010); Santamaría et al. (2012); Confente et al. (2015); Hussain, (2019)
	Insufficient infrastructure / Lack of IT infrastructure	Huxtable & Schaefer (2016); Kamble et al. (2018); Klein et

Technological		al. (2018); Adams (2019); Hussain, (2019); Zambetti et al. (2020)
	Problems for adapting new technology	Klein et al. (2018); Paschou et al. (2018); Mittal et al. (2018); Hussain, (2019)
	Data security problems	Davies (2015); Huxtable & Schaefer (2016); Thoben et al. (2017); Kamble et al. (2018); Hussain, (2019)
	Lack of adapting human-machine interaction	Lee et al. (2014); Thoben et al. (2017);
	Uncontrollable digitized machine performance	Lee et al. (2014)
	Parameter incongruence	Lee et al. (2014); Schroeder et al. (2016)

Servitization is an effective way to gain a competitive advantage for companies. However, companies that want to adopt this type of strategy face major barriers (Turunen & Finne, 2014). We divided the barriers encountered in our study into three main groups (see Table 4).

The first main barrier group of the servitization is ***financial barriers***, and these barriers are generally seen as difficult to overcome (Confente et al., 2015). In order for companies to transition to Industry 4.0 technologies, they need large financial investments (Davies, 2015). Companies that do not make the necessary investments in technology and have limited financial resources cannot benefit from all opportunities in digitalization (Schroeder et al., 2016). Moreover, the integration of technology with servitization has created some difficulties in costs and investments and made it difficult to measure return on investment (Marcon et al., 2019). Investments constitute an important problem due to the limited profit margins, and this situation makes it more difficult to invest (Confente et al., 2015).

Another barrier to a successful servitization process is a lack of ***information and capability.*** The human and information factors are crucial in servitization. Therefore, lack of information significantly affects the success of companies. Sustainable and integrated solutions are required for long-term strategies to be implemented. Besides, insufficient information about customer needs affects the progress of the processes (Michalik et al., 2019). Close contact with the customer is seen as a means of understanding customers' needs correctly (Marcon et al., 2019).

The lack of qualified employees is another factor that directly affects the performance of companies (Brax, 2005). In general, it has been observed that digital technologies drive Industry 4.0 services. In this context, companies that want to provide and design such services need qualified employees (Huxtable & Schaefer, 2016). Employees who can transition to the Industry 4.0 process are among the primary needs of employers. These types of employees, who have characteristics such as decision making and creativity, are also expected to have technical and ICT expertise (Davies, 2015). Lack of these skills adversely affects the success of service delivery (Huxtable & Schaefer, 2016).

Insufficient collaboration between companies affects the competitive environment. Companies providing servicing are in coordination with their suppliers and other companies. Therefore, any break in communication will harm companies (Confente et al., 2015).

Technological barriers were not seen as a major concern by most authors and, very few barriers have been mentioned in the use of digital information (Michalik et al., 2019). However, we attach great importance to technological barriers in this work.

For people to adapt to new technologies, they must first be convinced. If they are not convinced, they do not want to use this technology and cause the process to slow down (Hussain, 2019). Also, a lack of IT infrastructure will prevent a fast and reliable internet connection required by customers and machines (Huxtable & Schaefer, 2016). Companies should alert their current processes to reflect the needs of their customers, and IT capabilities are required to deliver these services (Klein et al., 2018).

There is a large amount of information flow in Industry 4.0 applications, so it faces cybersecurity threats and privacy problems of data (Hussain, 2019). In particular, the basis of the competitive advantage of production companies is production data. For this reason, the data in the systems must be carefully protected. Also, any access to the machine and control systems from outside the company will create a significant security problem (Thoben et al., 2017). The two most important factors affecting machine performance are human operation and management. A smart machine system is expected to increase productivity and production quality efficiency (Lee et al., 2014).

While the basic parameters are captured digitally, they may differ greatly depending on the measurement units and thresholds used from time to time. This inconsistency prevents data obtained from different sources from being interpreted consistently (Schroeder et al., 2016).

CHAPTER 5
METHODOLOGY

Problems with multiple alternatives and features can only be solved with multi-criteria decision-making (MCDM) tools (Awang et al., 2019). In other words, MCDM methods are defined as the way of making the most appropriate decision in the presence of multiple conflicting criteria (Chakraborty et al., 2013).

Researchers have developed various MCDM methods to make the best decision on problems involving multiple criteria. These methods were frequently compared with each other by the experts of the subject, and the most appropriate decision-making methods were tried to be selected for the problems (Karaoğlan & Şahin, 2016). Each MCDM method has many advantages and specialties to solve real complex problems (Awang et al., 2019). However, the number and variety of MCDM methods have sometimes confused potential decision-makers (Chakraborty et al., 2013). The most widely used MCDM methods developed are shown below (Awang et al., 2019).

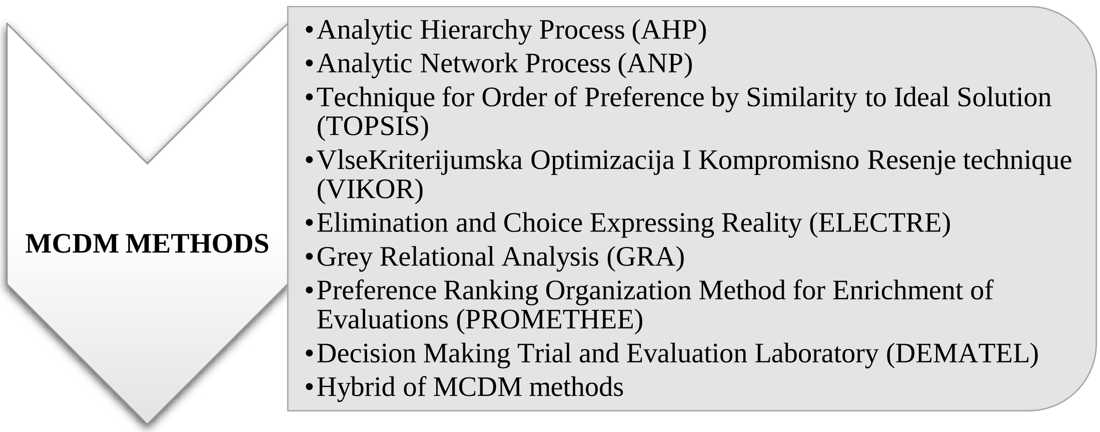

Figure 5.1. MCDM Methods

Source: Awang et al., 2019

Each MCDM problem is represented by a matrix *(X)* forming of $"m"$ alternatives and $"n"$ criteria (Chakraborty et al., 2013).

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}_{mxn} \qquad (1)$$

Kumar et al. (2017) mentioned a common procedure for MCDM analysis in their study.

- Defining a system with goals to be achieved
- Finding all the criteria that affect the system according to the goals
- Seeking alternative systems to feed the need of goals
- Setting priority/ weights to alternatives
- Choosing the MCDM method for the purpose
- Finding and presenting the most suitable alternative for evaluation

In the next section, information will be given about the DEMATEL, fuzzy logic and Fuzzy DEMATEL methods.

5.1 Fuzzy DEMATEL Method

5.1.1 DEMATEL Method

DEMATEL is a method developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976. The main purpose of this method is to investigate and solve complex and intertwined problem groups (Fontela & Gabus, 1974; Fontela & Gabus, 1976).

The DEMATEL method enables the relationship between the causes and effects of the criteria to transform the system into an understandable structural model (Falatoonitoosi et al., 2013). In other words, the DEMATEL method analyzes the total relationship between the structural components of a research system, then organizing them into cause and effect groups, thus providing a better understanding of the relationships. Also, this method enables the discovery of the most suitable solution for solving complex system problems (Mahmoudi et al., 2019).

Especially in Japan, DEMATEL is a very popular method. The reason for this is that it creates a structural model that includes causal relationships between complex factors and helps them to be analyzed later (Wu, 2008; Chang et al., 2011).

DEMATEL is based on graph theory that provides visual planning and solving of problems. In brief, it helps to develop a graph to reflect these relationships as well as verify the interdependence between variables (Li & Tzeng, 2009). This method has been widely used in researches as it helps to visualize the complex causal structure among many factors (Zhou et al., 2011). For instance;

- Using a combined ANP and DEMATEL approach to select knowledge management strategies (Wu, 2008)
- To determine the main success factors of hospital service quality (Shieh et al., 2010)
- To identify critical success factors in emergency management (Li et al., 2014)

For DEMATEL to be applied without any problems, Wu et al. (2008) developed the application version used by Fontela and Gabus (1976) and suggested five basic steps shown below. The necessary steps to apply the DEMATEL method are explained as follows.

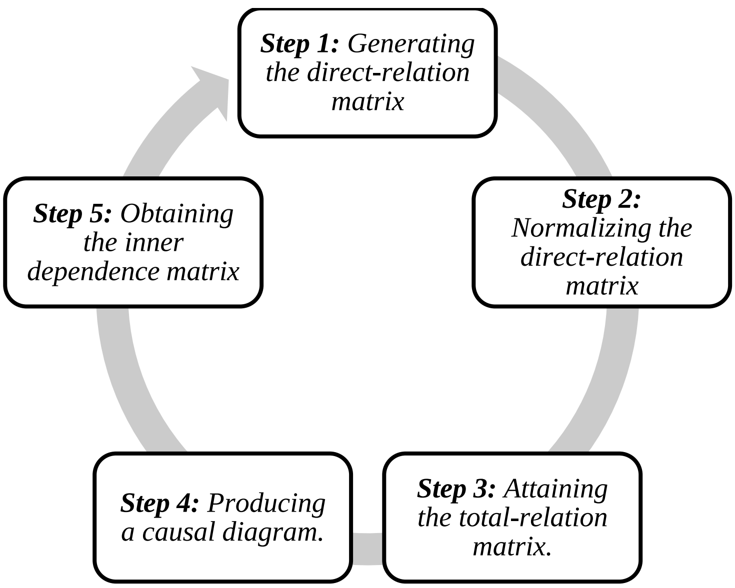

Figure 5.2. Steps of DEMATEL

Source: Wu, 2008

Step 1: Generating the direct-relation matrix

To measure the relationship between the criteria, the comparison scale should be designed as four levels (see Table 5.1). Then the experts perform a pairwise comparison sequence in terms of influence and direction between the specified criteria. As a result of these evaluations, a direct relationship matrix is obtained with initial data, which is an ***n.n matrix*** *A*. In which aij is expressed as the degree to which the criterion *i* affects the criterion *j*.

Table 5.1. Pairwise Comparison Scale

Levels	Influences
0	No influence
1	Low influence
2	High influence
3	Very high influence

Source: Wu, 2008

Step 2: Normalizing the direct-relation matrix

Based on direct relationship matrix ***A***, the normalized direct relationship matrix ***X*** can be obtained by the following formulas:

$$\boldsymbol{X} = k \cdot \boldsymbol{A} \tag{2}$$

$$k = \frac{1}{\max\limits_{1 \leqslant i \leqslant n} \sum_{j=1}^{n} a_{ij}}, \quad i, j = 1, 2, \ldots, n \tag{3}$$

Step 3: Attaining the total-relation matrix

After obtaining the normalized direct relationship matrix ***X***, the total relationship matrix ***T*** can be obtained using formula **(4)** where ***I*** is denoted as the identity matrix:

$$\boldsymbol{T} = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1} \tag{4}$$

Step 4: Producing a causal diagram

The sum of rows and the sum of columns are separately denoted as vector ***D*** and vector ***R*** using formulas **(5), (6),** and **(7).** Next, the horizontal axis vector **(D + R)** called "Prominence" is made by adding **D to R**, which reveals how important the criterion is. In a similar way, the vertical axis **(D - R)** called "Relation" is made by subtracting **D from R,** which can divide the criteria into a group of cause and a group of effect.

In general, for the criteria to belong to the cause group, **(D - R)** must be positive. In cases where **(D - R)** is negative, the criteria belong to the effect group. Thus, a causal diagram is obtained by mapping the **(D + R, D - R)** data set and provides important information in making a decision.

$$\boldsymbol{T} = [t_{ij}]_{n \times n}, \quad i, j = 1, 2, ..., n \tag{5}$$

$$\boldsymbol{D} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} = [t_{i \cdot}]_{n \times 1} \tag{6}$$

$$\boldsymbol{R} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1 \times n}^{t} = [t_{\cdot j}]_{n \times 1} \tag{7}$$

The vector D and the vector R show the sum of rows and the sum of columns from the total relation matrix $\boldsymbol{T} = [t_{ij}]_{n \times n}$, respectively.

Step 5: Obtaining the inner dependence matrix

In the last step, the sum of each column in the total-relation matrix is equal to **1** by the normalization method, and then the inner dependence matrix can be obtained.

5.1.2 Fuzzy Logic

The uncertainties in the real-life problems experienced and the difficulties experienced in digitizing the verbal evaluation methods can be solved by using fuzzy methods.

Decision-makers express relationship values with verbal expressions, and fuzzy numbers help to convert these expressions to numerical expressions correctly. For this reason, the use of fuzzy methods in solving real-life problems has become widespread today (Kabadayı & Dağ, 2017).

Zadeh (1965) states that complex world problems become even more complex when combined with people's thoughts. Also, Zadeh proposed the concept of fuzzy set theory and introduced the membership function to better understand this uncertainty. Fuzzy logic provides mathematical expression of subjective, imprecise, and ambiguous relationships. Each number between 0 and 1 indicates a partial reality (Al-Najjar & Alsyouf, 2003).

Problems in group decision making are the basis of the generation of fuzzy numbers. A triangular fuzzy number is expressed as $\tilde{A}$ = (l, m, u), where l, m, and u represents lower, medium and upper number of the fuzzy, which is crisp and real numbers ($x \leq y \leq z$) (Başhan & Demirel, 2019).

$$\mu\tilde{A} = \begin{cases} 0, & x < l \\ (x - l)/(m - l), & l \leq x \leq m \\ (u - x)/(u - m), & m \leq x \leq u \\ 0, & x \geq u \end{cases} \tag{8}$$

Linguistic variables make the statements of decision-makers in their evaluations more understandable. Suitable for bad and unmanageable situations, these linguistic variables are represented by fuzzy numbers. The most commonly used are triangular fuzzy numbers (Lin & Wu, 2008).

In general, the fuzzy linguistic terms proposed by Li (1999) is used in group decision making.

Table 5.2. Linguistic Terms and Triangular Fuzzy Numbers

Linguistic Terms	Triangular Fuzzy Numbers
No influence (NO)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.50)
Low influence (L)	(0.25, 0.50, 0.75)
High influence (H)	(0.50, 0.75, 1.00)
Very high influence (VH)	(0.75, 1.00, 1.00)

Source: Li, 1999

To make better decisions in unstable and fuzzy environments, the need to expand methods with fuzzy logic has arisen (Wu & Lee, 2008). The fuzzy DEMATEL method, which arises from this need, was chosen as the most appropriate method for our study.

5.1.3 Fuzzy DEMATEL

Cause and effect relationships are often complex, and the uncertainty in human life makes this relationship more difficult. Therefore, a method is needed to understand the causal relationship in fuzzy environments (Lin & Wu, 2008).

The fuzzy DEMATEL method is a common method applied in many fields and by many authors. For instance, Zhou et al. (2011) to determination of critical success factors in emergency management, Chang et al. (2011) to improve supplier selection criteria, and Başhan & Demirel (2019) to evaluate the most common critical operational failures of ship boilers used the fuzzy DEMATEL method.

Chen-Yi et al. (2007), Yeh & Huang (2014) mentioned the steps of the application while explaining the fuzzy DEMATEL method in their studies. These steps are:

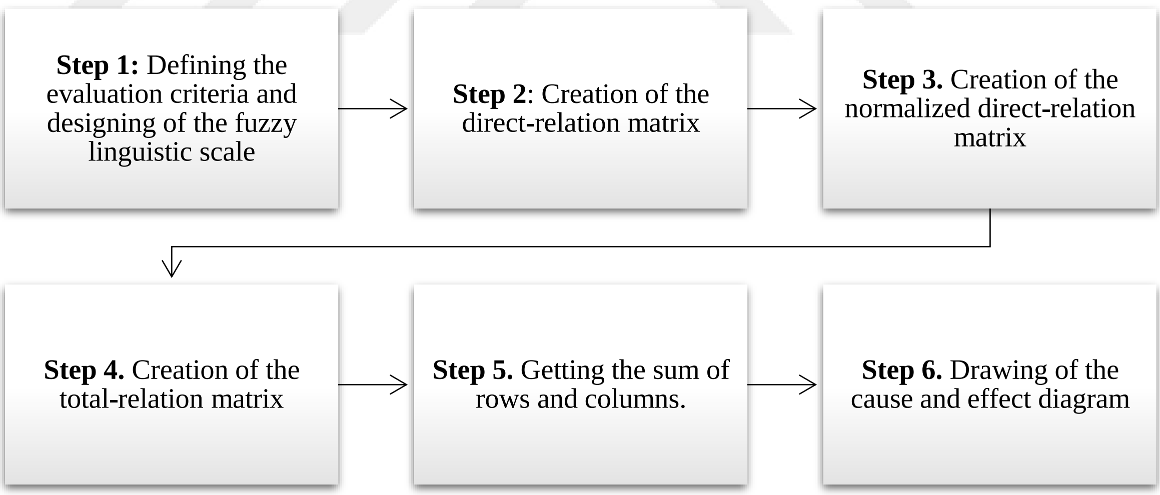

Figure 5.3 Steps of Fuzzy DEMATEL

Source: Chen-Yi et al. (2007); Yeh & Huang (2014)

Step 1: Defining the evaluation criteria and designing of the fuzzy linguistic scale

It is the step of expressing the transformation of human logic into numerical expressions. In this step, linguistic variables suggested by Li (1999) are used (see Table 5.2).

Step 2: Creation of the direct-relation matrix Z

Pairwise comparisons between specified criteria are made by a group of decision-makers and, the initial direct-relation matrix is obtained.

$$\tilde{Z} = \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} \begin{bmatrix} 0 & \tilde{Z}_{12} & \cdots & \tilde{Z}_{1n} \\ \tilde{Z}_{21} & 0 & \cdots & \tilde{Z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{Z}_{n1} & \tilde{Z}_{n2} & \cdots & 0 \end{bmatrix} \quad (9)$$

$$Z_{ij} = (l_{ij} , m_{ij}, n_{ij})$$

Step 3. Creation of the normalized direct-relation matrix X

The linear scale is converted into a normalization formula so that the criteria scale can be converted into comparable scales.

$$\tilde{a}_{ij} = \sum_{j=1}^{n} \tilde{Z}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} r_{ij} \right) \text{ and } r = \max_{1 \le i \le n} \left(\sum_{j=1}^{n} r_{ij} \right) \quad (10)$$

A normalized direct-relation fuzzy matrix for X is calculated as follows.

$$\tilde{X} = \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \cdots & \tilde{X}_{mn} \end{bmatrix} \text{ and } \tilde{X}_{ij} = \frac{\tilde{Z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{r_{ij}}{r} \right) \quad (11)$$

Step 4. Creation of the total-relation matrix T

After the normalized direct- relation matrix X has been created, the total-relation matrix T can be constructed from the following equations.

$$\begin{aligned} \tilde{T} &= \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^k = \tilde{X}\left(I + \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^{k-1}\right) \\ &= \tilde{X}\left(I + \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^{k-1}\right)\left(I - \tilde{X}\right)\left(I - \tilde{X}\right)^{-1} \\ &= \tilde{X}\left(I - \tilde{X}\right)^{-1}, \text{ when } \lim_{k \to \infty} \tilde{X}^k = [0]_{nxn} \end{aligned}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{m1} & \tilde{t}_{m2} & \cdots & \tilde{t}_{mn} \end{bmatrix} \text{ and } \tilde{t}_{ij} = \left(l''_{ij}, m''_{ij}, r''_{ij}\right)$$

$$\left[l''_{ij}\right] = X_l \times (I - X_l)^{-1}$$

$$\left[m''_{ij}\right] = X_m \times (I - X_m)^{-1}$$

$$\left[r''_{ij}\right] = X_r \times (I - X_r)^{-1} \quad (12)$$

Step 5. Getting the sum of rows and columns

Row and column values are taken from equation (13) and defined as D and R.

$$T = [t_{ij}], \quad i,j \in \{1, 2, \ldots, n\}$$

$$d = (d_i)_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \; ; \; r = (r_j)'_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} \quad (13)$$

Step 6. Drawing of the cause and effect diagram

After calculating D + R and D - R, correlations between criteria are analyzed by diagram D + R represents effects between criteria, while a higher value means a greater effect. D - R represents causal relationships between criteria. A higher value means that the criteria are the causes of the other criteria, and the lower one is the results of the other criteria.

CHAPTER 6
IMPLEMENTATION OF THE STUDY

Industry 4.0 is a set of applications that are widely used by companies today. The tendency of companies engaged in servicing activities towards such practices brings some problems. This section includes the fuzzy DEMATEL method used to evaluate the barriers encountered by service providers during industry 4.0 applications. Decision-makers were asked to evaluate the 12 critical barriers obtained as a result of the literature review. The opinions of 7 decision-makers were used for this study.

This study, which includes the analysis of the barriers in servitization and Industry 4.0 applications, was completed by experts from different companies and different positions. 7 people working in 7 different service companies in İzmir were selected for this study. This group of experts is people with at least 1 year of experience working as experts in different service sectors. Experts are involved in the food, logistics, customs and automotive industries.

While forming an expert group in this study, people who have sectoral knowledge and who can contribute to the study with their experiences were selected. Information on experts is given in Table 6.1.

Table 6.1. Information on Experts

Expert	Sector	Area of Expertise	Experience	Gender
1	Food	Warehouse and Logistics	2 years	Male
2	Logistics	Operation	1 year	Female
3	Logistics	Operation	1 year	Female
4	Customs	Customs Consultant/ Foreign Marketing	>30 years	Male
5	Logistics	Supply	4 years	Male
6	Automotive	Sales	1 year	Female
7	Logistics	Marketing	2 years	Male

6.1 Purpose of the Study

The purpose of this study is to analyze the effect of the barriers faced by companies engaged in servitization activities in industry 4.0 applications using the fuzzy DEMATEL method. In this direction, the opinions of experts working in companies that both provide services and apply or try to apply industry 4.0 technologies in their processes have been used. As a result of the literature review, 12 criteria were obtained, and these criteria were directed to 7 decision-makers.

Experts working in companies that started to apply Industry 4.0 technologies helped us determine the weights of 12 criteria via e-mail. Between February 1 and March 1, 2021, an Excel file containing the criteria was sent to 7 experts by e-mail and from all of them received feedback.

The criteria obtained as a result of the literature review and evaluated by the experts in our study are summarized in Table 6.2.

Tablo 6.2 Criteria and Explanation

Criteria		Explanation
C1	Lack of financial resources	Industry 4.0 technologies require large amounts of financial resources (Horváth & Szabó, 2019), so lack of financial resources lead to implementation failure.
C2	Costs and investments/ High Implementation Cost	Companies need large financial investments to be able to apply Industry 4.0 technologies (Davies, 2015). High implementation costs and investments constitutes a major barrier.
C3	Insufficient information about customers' needs	Insufficient information about customer needs is an important barrier to the progress of processes (Michalik et al., 2019).
C4	Lack of qualified employees	One of the major barriers to be faced during the implementation of Industry 4.0 technologies was that companies did not have qualified employees with the skills that would be required now and in the future. Because, retraining the employees will be

		both time consuming and cost increasing (Horváth & Szabó, 2019)
C5	Lack of information/ knowledge	Sustainable and integrated solutions are needed for the implementation of long-term strategies, the lack of knowledge required for these solutions is an important barrier (Michalik et al., 2019).
C6	Insufficient collaboration-cooperation / Coordination problems	Companies should be in coordination with their suppliers and other companies, and any disruption in communication will harm companies (Confente et al., 2015).
C7	Insufficient infrastructure / Lack of IT infrastructure	Changes in the needs of customers increase the need for IT infrastructures in service delivery and lack of IT infrastructures cause them to fail to provide these services (Klein et al., 2018).
C8	Problems for adapting new technology	The inability of people to adapt to new technologies will cause processes to slow down (Hussain, 2019).
C9	Data security problems	The data in the systems must be carefully protected against any threat that may be encountered (Thoben et al., 2017)., any data security problem will affect companies negatively.
C10	Lack of adapting human-machine interaction	The most important and effective factor for machine performance is human operation and management (Lee et al., 2014). Therefore, the lack of human-machine interaction will cause failure.
C11	Uncontrollable digitized machine performance	Uncontrollable digitized machine performance will hinder the proper execution of applications such as product quality measurement (Lee et al., 2014).
C12	Parameter incongruence	Incongruence between parameters prevent data obtained from different sources from being interpreted consistently (Schroeder et al., 2016).

6.2 Implementation of the Fuzzy DEMATEL

Step 1: Defining the evaluation criteria and designing of the fuzzy linguistic scale

The determined criteria were evaluated with linguistic variables by seven decision-makers. They were asked to make pairwise comparisons between these criteria, and then the statements of each decision-maker were entered into the system through the Excel program. In this step, linguistic variables suggested by Li (1999) were used (see Table 5.2).

Step 2: Creation of the direct-relation matrix Z

Relationships between criteria have been evaluated by decision-makers. The group decision obtained as a result of these evaluations has been transformed into expressions corresponding to triangular fuzzy numbers. The direct relation matrix Z obtained is shown in Table 6.3.

Table 6.3 The direct-relation matrix Z

Z	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**
C1	0,033	0,933	0,467	0,767	0,400	0,500	0,800	0,667	0,600	0,567	0,567	0,400
C2	0,767	0,033	0,400	0,733	0,300	0,333	0,600	0,267	0,400	0,500	0,500	0,400
C3	0,233	0,533	0,033	0,500	0,833	0,767	0,567	0,433	0,400	0,333	0,333	0,600
C4	0,500	0,633	0,700	0,033	0,900	0,800	0,633	0,733	0,667	0,467	0,467	0,667
C5	0,667	0,767	0,833	0,767	0,033	0,867	0,800	0,767	0,833	0,633	0,633	0,733
C6	0,567	0,667	0,767	0,633	0,667	0,033	0,500	0,667	0,533	0,567	0,567	0,600
C7	0,767	0,833	0,867	0,733	0,867	0,533	0,033	0,833	0,900	0,833	0,833	0,800
C8	0,567	0,667	0,667	0,567	0,900	0,633	0,867	0,033	0,700	0,867	0,867	0,733
C9	0,567	0,600	0,467	0,367	0,667	0,567	0,733	0,700	0,033	0,567	0,567	0,733
C10	0,500	0,600	0,433	0,600	0,733	0,600	0,667	0,867	0,500	0,867	0,867	0,767
C11	0,400	0,467	0,333	0,600	0,633	0,500	0,567	0,733	0,600	0,033	0,033	0,833
C12	0,500	0,500	0,733	0,433	0,733	0,567	0,567	0,667	0,700	0,767	0,767	0,033

Step 3. Creation of the normalized direct-relation matrix X

The normalized-relation matrix was created using equations 10 and 11. The data obtained are shown in Table 6.4.

Table 6.4 The normalized direct-relation matrix X

X	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**
C1	0,000	0,106	0,053	0,087	0,045	0,057	0,091	0,075	0,068	0,064	0,064	0,045
C2	0,087	0,000	0,045	0,083	0,034	0,038	0,068	0,030	0,045	0,057	0,057	0,045
C3	0,026	0,060	0,000	0,057	0,094	0,087	0,064	0,049	0,045	0,038	0,038	0,068
C4	0,057	0,072	0,079	0,000	0,102	0,091	0,072	0,083	0,075	0,053	0,053	0,075
C5	0,075	0,087	0,094	0,087	0,000	0,098	0,091	0,087	0,094	0,072	0,072	0,083
C6	0,064	0,075	0,087	0,072	0,075	0,000	0,057	0,075	0,060	0,064	0,064	0,068
C7	0,087	0,094	0,098	0,083	0,098	0,060	0,000	0,094	0,102	0,094	0,094	0,091
C8	0,064	0,075	0,075	0,064	0,102	0,072	0,098	0,000	0,079	0,098	0,098	0,083
C9	0,064	0,068	0,053	0,042	0,075	0,064	0,083	0,079	0,000	0,064	0,064	0,083
C10	0,057	0,068	0,049	0,068	0,083	0,068	0,075	0,098	0,057	0,000	0,098	0,087
C11	0,045	0,053	0,038	0,068	0,072	0,057	0,064	0,083	0,068	0,004	0,000	0,094
C12	0,057	0,057	0,083	0,049	0,083	0,064	0,064	0,075	0,079	0,087	0,087	0,000

Step 4. Creation of the total-relation matrix T

The total-relation matrix is created with the formulas in equation 12. These data are shown in Table 6.5.

Tablo 6.5 The total-relation matrix T

T	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**
C1	0,205	0,336	0,274	0,305	0,297	0,275	0,326	0,313	0,293	0,268	0,293	0,285
C2	0,242	0,190	0,220	0,255	0,233	0,213	0,256	0,223	0,225	0,217	0,237	0,234
C3	0,201	0,260	0,194	0,244	0,303	0,271	0,266	0,254	0,240	0,214	0,235	0,270
C4	0,274	0,325	0,318	0,242	0,367	0,326	0,329	0,339	0,319	0,276	0,301	0,332
C5	0,321	0,374	0,363	0,355	0,312	0,364	0,381	0,378	0,368	0,322	0,352	0,374
C6	0,265	0,311	0,306	0,292	0,326	0,225	0,298	0,314	0,288	0,269	0,294	0,307
C7	0,344	0,396	0,380	0,366	0,418	0,346	0,315	0,401	0,390	0,355	0,388	0,397
C8	0,305	0,357	0,340	0,329	0,398	0,335	0,381	0,293	0,350	0,339	0,371	0,369
C9	0,264	0,301	0,274	0,263	0,322	0,281	0,318	0,315	0,229	0,268	0,293	0,318
C10	0,274	0,320	0,289	0,305	0,350	0,304	0,332	0,353	0,302	0,224	0,342	0,342
C11	0,223	0,260	0,235	0,259	0,290	0,249	0,273	0,290	0,267	0,190	0,204	0,299
C12	0,265	0,302	0,310	0,279	0,341	0,293	0,313	0,324	0,312	0,295	0,323	0,253

Step 5. Getting the sum of rows and columns

After the total relationship matrix was created, the values of R were found by summing column elements and adding D and row elements.

Table 6.6. The Degree of Central Role

Criteria	D	R	D+R	D-R
C1	3,470785	3,1832	6,65395	0,28762
C2	2,745623	3,7326	6,47827	-0,7812
C3	2,951435	3,50162	6,45306	0,24661
C4	3,748225	3,495	7,24299	0,77095
C5	4,265715	3,9562	8,22195	-0,4606
C6	3,495646	3,48306	6,9787	1,01371
C7	4,496767	3,7886	8,28535	0,37764
C8	4,166221	3,7969	7,96315	-0,352781942
C9	3,444156	3,58117	7,02533	0,15479
C10	3,735959	3,235294	6,97125	-0,1953
C11	3,039949	3,633348	6,6733	-0,0254
C12	3,607996	3,781647	7,38964	-0,1737

The relationships between criteria are analyzed by showing the found D + R and D-R values on a diagram (see Figure 6.7)

Table 6.7. Cause and Effect Group

D-R (+) Cause Group: C1, C3, C4, C6, C7, C9
D-R (-) Effect Group: C2, C5, C8, C10, C11, C12
Importance order (descending): C7, C5, C8, C12, C4, C9, C6, C10, C11, C1, C2, C3

Step 6. Drawing of the Cause and Effect Diagram

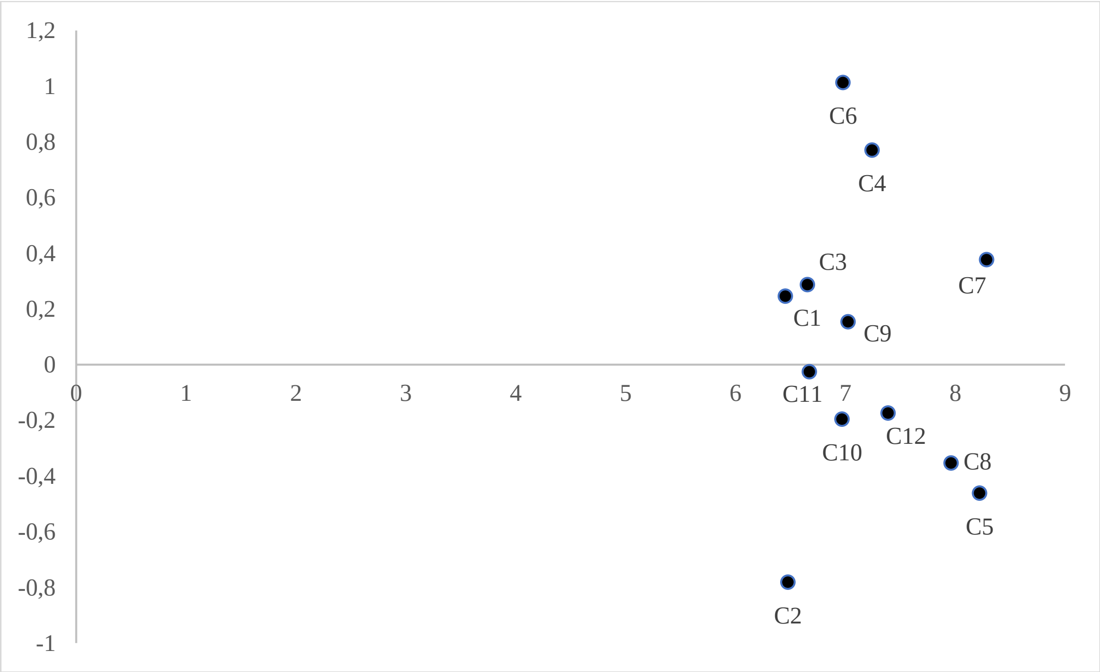

Figure 6.1 The Cause-and-Effect Relationship Diagram

Figure 6.1 shows that among the determined critical barriers, C1, C3, C4, C6, C7, C9 are in the cause group, and C2, C5, C8, C10, C11, C12 criteria are in the effect group. In order of importance, it was determined that the criterion with the highest importance was C7 (Insufficient infrastructure / Lack of IT infrastructure), and it was concluded that the most influencing factor were C6 (Insufficient collaboration-cooperation / Coordination problems). The most affected criterion is the C2 criterion in the effect group.

CHAPTER 7
CONCLUSIONS

Servitization is seen as a means of competition among companies and means providing value by adding services to products. According to Vandermerwe and Rada (1988), the concept of servitization has gone through 3 stages over time. These are respectively; *(i) Goods or Services, (ii) Goods + Services, (iii) Goods + Services + Support + Self Service + Knowledge.*

With the developing technology, there has been a transition to smart systems and applications, especially in manufacturing companies. Industry 4.0, which plays a significant role in the success of companies, has enabled new opportunities. Over time, researchers and authors have carried out many studies that address these two issues separately. However, we focused on the integration of these two concepts in our study.

This study focused on industry 4.0 and servitization concepts and evaluated servitization in terms of industry 4.0. Increasing interest in Industry 4.0 applications has created a competitive environment among companies. This situation led companies to adopt these practices, but some barriers were encountered during these applications.

MCDM methods describe the methods developed to evaluate and analyze all the criteria that affect decisions. In this direction, many methods have been developed by the researchers and used widely in studies. Among these methods, Fuzzy DEMATEL was chosen as the best method suitable for our study. This method determines the importance order of the criteria as well as revealing the cause-and-effect relationship between the criteria. The fuzzy DEMATEL method, which enables uncertain human thoughts to be expressed numerically, has made an important contribution to our study.

With the literature review, the barriers that companies performing servitization activities will encounter in industry 4.0 applications have been determined. The Fuzzy DEMATEL method was applied to determine the cause-and-effect relationships among these barriers and to reveal the importance order of these barriers for companies. This study, which evaluated 12 critical barriers obtained by literature review, was completed with the contribution of 7 experts. To complete the study, the opinions of 7 experts working in different companies operating in İzmir were taken into consideration. This group of experts consists of people with at least one year of experience working in the food, logistics, automotive, and customs sectors. An e-mail was sent to each of them between February 1 and March 1, 2021 to get the opinions of the expert group and, feedback was provided. The opinion of each expert was evaluated one by one and, then the group decision was analyzed.

The barriers faced by companies engaged in servitization activities during industry 4.0 applications, respectively, Insufficient infrastructure / Lack of IT infrastructure (C7), Lack of information/ knowledge (C5), Problems for adapting new technology (C8), Parameter incongruence (C12), Lack of qualified employees (C4), Data security problems (C9), Insufficient collaboration- cooperation / Coordination problems (C6), Lack of adapting human-machine interaction (C10), Uncontrollable digitized machine performance(C11), Lack of financial resources (C1), Costs and investments/ High Implementation Cost (C2), Insufficient information about customers' needs (C3).

It was determined that the cause group in the barriers encountered in industry 4.0 applications is C1, C3, C4, C6, C7, C9 criteria. The effect group is C2, C5, C8, C10, C11, C12. Our implementation results show that C7 have the highest importance among the barriers for industry 4.0 application. The most influencing criteria is C6, and the most affected criteria is C2.

The Fuzzy DEMATEL method used in this study will be a guide for future studies using MCDM methods and, this study will also contribute to the literature on servitization and industry 4.0 issues.

REFERENCES

Abou-foul, M., Ruiz-Alba, J. L., & Soares, A. (2020). The impact of digitalization and servitization on the financial performance of a firm: an empirical analysis. *Production Planning & Control*, 1-15.

Adams, K. (2019). *Servitization: Critical factors for successful implementation* (Bachelor's thesis, University of Twente).

Ahamed, Z., Inohara, T., & Kamoshida, A. (2013). The servitization of manufacturing: An empirical case study of IBM corporation. *International journal of business administration*, *4*(2), 18-26.

Al-Najjar, B., & Alsyouf, I. (2003). Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making. *International journal of production economics*, *84*(1), 85-100.

Ardolino, M., Saccani, N., Gaiardelli, P., & Rapaccini, M. (2016). Digital technologies and their impacts on servitization strategies. In *Proceedings of the Spring Servitization Conference (SSC2016)* (pp. 83-91).

Awang, A., Aizam, N. A. H., & Abdullah, L. (2019). An integrated decision-making method based on neutrosophic numbers for investigating factors of coastal erosion. *Symmetry*, *11*(3), 328.

Ayala, N. F., Paslauski, C. A., Ghezzi, A., & Frank, A. G. (2017). Knowledge sharing dynamics in service suppliers' involvement for servitization of manufacturing companies. *International Journal of Production Economics*, *193*, 538-553.

Baines, T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., ... & Alcock, J. R. (2007). State-of-the-art in product-service systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *221*(10), 1543-1552.

Baines, T. S., Lightfoot, H. W., Benedettini, O., & Kay, J. M. (2009). The servitization of manufacturing: A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management*, *20*(5), 547–567.

Baines, T., & Lightfoot, H. W. (2013). Servitization of the manufacturing firm: Exploring the operations practices and technologies that deliver advanced services. *International Journal of Operations & Production Management*, *34*(1), 2-35.

Baines, T., Bigdeli, A. Z., Sousa, R., & Schroeder, A. (2020). Framing the servitization transformation process: A model to understand and facilitate the servitization journey. *International Journal of Production Economics*, *221*, 107463.

Başhan, V., & Demirel, H. (2019). Application of fuzzy dematel technique to assess most common critical operational faults of marine boilers. *Politeknik Dergisi*, *22*(3), 545-555.

Beuren, F. H., Ferreira, M. G. G., & Miguel, P. A. C. (2013). Product-service systems: a literature review on integrated products and services. *Journal of Cleaner Production*, *47*, 222-231.

Buhr, D. (2015). *Social innovation policy for Industry 4.0*. Friedrich-Ebert-Stiftung, Division for Social and Economic Policies.

Bortoluzzi, G., Chiarvesio, M., Romanello, R., Tabacco, R., & Veglio, V. (2020). Industry 4.0 technologies and the servitization strategy: a good match? *Sinergie Italian Journal of Management*, *38*(1), 55-72.

Brax, S. (2005), "A manufacturer becoming service provider – challenges and a paradox", *Managing Service Quality: An International Journal*, Vol. 15 No. 2, pp. 142-155.

Bustinza, O. F., Bigdeli, A. Z., Baines, T., & Elliot, C. (2015). Servitization and competitive advantage: the importance of organizational structure and value chain position. *Research-Technology Management*, *58*(5), 53-60.

Calabrese, A., Levialdi Ghiron, N., Tiburzi, L., Baines, T., & Ziaee Bigdeli, A. (2019). The measurement of degree of servitization: literature review and recommendations. *Production Planning & Control*, *30*(13), 1118-1135.

Calabretta, G., De Lille, C., Beck, C., & Tanghe, J. (2016, May). Service Design for Effective Servitization and New Service Implementation. In *Service Design Geographies. Proceedings of the ServDes. 2016 Conference* (No. 125, pp. 91-104). Linköping University Electronic Press.

Caldeira, M. M., & Ward, J. M. (2003). Using resource-based theory to interpret the successful adoption and use of information systems and technology in manufacturing small and medium-sized enterprises. *European Journal of information systems*, *12*(2), 127-141.

Chakraborty, R., Ray, A., & Dan, P. (2013). Multi criteria decision making methods for location selection of distribution centers. *International Journal of Industrial Engineering Computations*, *4*(4), 491-504.

Chang, B., Chang, C. W., & Wu, C. H. (2011). Fuzzy DEMATEL method for developing supplier selection criteria. *Expert systems with Applications*, *38*(3), 1850-1858.

Chen-Yi, H., Ke-Ting, C., & Gwo-Hshiung, T. (2007). FMCDM with Fuzzy DEMATEL Approach for Customers' Choice Behavior Model. *International Journal of Fuzzy Systems*, *9*(4).

Chiarini, A., Belvedere, V., & Grando, A. (2020). Industry 4.0 strategies and technological developments. An exploratory research from Italian manufacturing companies. *Production Planning & Control*, 1-14.

Cimini, C., Rondini, A., Pezzotta, G., & Pinto, R. (2018). Smart manufacturing as an enabler of servitization: a framework for the business transformation towards a smart service ecosystem. In *23rd Summer School" Francesco Turco"-Industrial Systems Engineering 2018, Palermo, 12-14 September 2018* (Vol. 2018, pp. 341-347). AIDI (Italian Association of Industrial Operations Professors).

Confente, I., Buratti, A., & Russo, I. (2015). The role of servitization for small firms: drivers versus barriers. *International Journal of Entrepreneurship and Small Business*, *26*(3), 312-331.

Crozet, M., & Milet, E. (2014). *The servitization of French manufacturing firms* (No. 2014-10).

Culot, G., Orzes, G., & Sartor, M. (2019). Integration and scale in the context of Industry 4.0: the evolving shapes of manufacturing value chains. *IEEE Engineering Management Review*, *47*(1), 45-51.

Culot, G., Orzes, G., Sartor, M., & Nassimbeni, G. (2020). The future of manufacturing: A Delphi-based scenario analysis on Industry 4.0. *Technological forecasting and social change*, *157*, 120092.

Davies, R. (2015). Industry 4.0 Digitalisation for productivity and growth. *European Parliamentary Research Service*, *1*.

De Propris, L. (2016). *A fourth industrial revolution is powering the rise of smart manufacturing*. London, UK: The Conversation Trust. Available at: https://theconversation.com/a-fourth-industrial-revolution-is-powering-the-rise-of-smart-manufacturing-57753

Dinges, V., Urmetzer, F., Martinez, V., Zaki, M., & Neely, A. (2015). The future of servitization: Technologies that will make a difference. *Cambridge Service Alliance, University of Cambridge, Cambridge*.

Doni, F., Corvino, A., & Martini, S. B. (2019). Servitization and sustainability actions. Evidence from European manufacturing companies. *Journal of environmental management*, *234*, 367-378.

Ennis, C., & Barnett, N. (2019). Industry 4.0: Exploring Collaborative Supply Networks from the Perspective of Servitization of a Mature Public Transport System. *Available at SSRN 3532254*.

Ennis, C., Barnett, N., De Cesare, S., & Lander, R. (2020). A conceptual framework for servitization in Industry 4.0: Distilling directions for future research. *Available at SSRN 3529276*.

Falatoonitoosi, E., Leman, Z., Sorooshian, S., & Salimi, M. (2013). Decision-making trial and evaluation laboratory. *Research Journal of Applied Sciences, Engineering and Technology*, *5*(13), 3476-3480.

Fontela, E., & Gabus, A. (1974). DEMATEL, Innovative Methods. Report No. 2, Structural analysis of the world problematique. Battelle Geneva Research Institute (Battelle Memorial Institute).

Fontela, E., & Gabus, A. (1976). *The DEMATEL observer, DEMATEL 1976 Report.* Switzerland Geneva: Battelle Geneva Research Center.

Frank, A. G., Mendes, G. H., Ayala, N. F., & Ghezzi, A. (2019). Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technological Forecasting and Social Change*, *141*, 341-351.

Gabus, A., & Fontela, E. (1972). World problems, an invitation to further thought within the framework of DEMATEL. *Battelle Geneva Research Center, Geneva, Switzerland*, 1-8.

Gartner Glossary, 2020. Digitalization [WWW Document]. URL https://www.gartner.com/en/information-technology/glossary/digitalization

Gebauer, H., Fleisch, E., & Friedli, T. (2005). Overcoming the service paradox in manufacturing companies. *European management journal*, *23*(1), 14-26.

Gebauer, H., Paiola, M., Saccani, N., & Rapaccini, M. (2020). Digital servitization: Crossing the perspectives of digitization and servitization.

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*.

Grandinetti, R., Ciasullo, M. V., Paiola, M., & Schiavone, F. (2020). Fourth industrial revolution, digital servitization and relationship quality in Italian B2B manufacturing firms. An exploratory study. *The TQM Journal*.

Ha, S. Y., Lee, G. H., & Kim, B. S. (2016). Strategies for manufacturing servitization of korean SMEs: By using data envelopment analysis. *Journal of Applied Business Research (JABR), 32*(2), 635-646.

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?. *Technological Forecasting and Social Change*, *146*, 119-132.

Hou, J., & Neely, A. (2013). Barriers of servitization: Results of a systematic literature review. *Frameworks and Analysis*, *189*.

Hudson, S., Roth, M. S., & Madden, T. J. (2012). Customer communications management in the new digital era. *Center for marketing studies, Darla moore school of business, University of south Carolina*, 21.

Huikkola, T., Kohtamäki, M., & Rabetino, R. (2016). Resource Realignment in Servitization: A study of successful service providers explores how manufacturers modify their resource bases in transitioning to service-oriented offerings. *Research-Technology Management*, *59*(4), 30-39.

Hussain, L. A. S. (2019). Investigation of Industry 4.0 technologies barriers and ability to enable inclusive and sustainable industrialization and fostering innovation in Sudan.

Huxtable, J., & Schaefer, D. (2016). On Servitization of the Manufacturing Industry in the UK. *Procedia CIRP*, *52*(1), 46-51.

Industry 4.0 Ready. ISITAN. (2020). Retrieved 11 October 2020, from https://www.isitan.com/en/technology-industry-40-ready.html.

Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. BCG Global. (2015). Retrieved 30 October 2020, from https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries

Iyer, R. (2019). *Powering the Servitization of Manufacturing with Industry 4.0* [Ebook]. Retrieved 23 November 2020, from https://www.lntinfotech.com/wp-content/uploads/2019/11/Powering-the-Servitization-of-Manufacturing-with-Industry-4.0.pdf.

Kabadayı, N., & Dağ, S. (2017). Bulanık DEMATEL ve Bulanık PROMETHEE Yöntemleri İle Kablo Üretiminde Makine Seçimi. *Karadeniz Teknik Üniversitesi Sosyal Bilimler Enstitüsü Sosyal Bilimler Dergisi*, *7*(14), 239-260.

Kamalaldin, A., Linde, L., Sjödin, D., & Parida, V. (2020). Transforming provider-customer relationships in digital servitization: A relational view on digitalization. *Industrial Marketing Management*.

Kamble, S. S., Gunasekaran, A., & Sharma, R. (2018). Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. *Computers in Industry*, *101*, 107-119.

Karaoğlan, S., & Şahin, S. (2016). DEMATEL ve AHP Yöntemleri ile İşletmelerin Satın Alma Problemine Bütünleşik Bir Yaklaşım, DSLR Kamera Örneği1. *İşletme Araştırmaları Dergisi*, *8*(2), 359-375.

Kharlamov, A. A., & Parry, G. (2020). The impact of servitization and digitization on productivity and profitability of the firm: a systematic approach. *Production Planning & Control*, 1-13.

Kindström, D., & Kowalkowski, C. (2014). Service innovation in product-centric firms: A multidimensional business model perspective. *Journal of Business & Industrial Marketing*.

Klein, M. M., Biehl, S. S., & Friedli, T. (2018). Barriers to smart services for manufacturing companies–an exploratory study in the capital goods industry. *Journal of Business & Industrial Marketing*.

Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H., & Baines, T. (2019). Digital servitization business models in ecosystems: A theory of the firm. *Journal of Business Research*, *104*, 380-392.

Kohtamäki, M., Parida, V., Patel, P. C., & Gebauer, H. (2020). The relationship between digitalization and servitization: The role of servitization in capturing the financial potential of digitalization. *Technological Forecasting and Social Change*, *151*, 119804.

Kowalkowski, C., Gebauer, H., & Oliva, R. (2017). Service growth in product firms: Past, present, and future. *Industrial Marketing Management*, *60*, 82-88.

Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renewable and Sustainable Energy Reviews*, *69*, 596-609.

Lee, J., Kao, H. A., & Yang, S. (2014). Service innovation and smart analytics for industry 4.0 and big data environment. *Procedia Cirp*, *16*(1), 3-8.

Lertsakthanakun, J., Thawesaengskulthai, N., & Pongpanich, C. (2012). Servitization decision-making framework for Thai manufacturing companies. *International Journal of Business and Management*, *7*(12), 147.

Li, R. J. (1999). Fuzzy method in group decision making. *Computers & Mathematics with Applications*, *38*(1), 91-101.

Li, C. W., & Tzeng, G. H. (2009). Identification of a threshold value for the DEMATEL method using the maximum mean de-entropy algorithm to find critical services provided by a semiconductor intellectual property mall. *Expert Systems with Applications*, *36*(6), 9891-9898.

Li, J. H., Lin, L., Chen, D. P., & Ma, L. Y. (2015). An empirical study of servitization paradox in China. *The Journal of High Technology Management Research*, *26*(1), 66-76.

Li, Y., Hu, Y., Zhang, X., Deng, Y., & Mahadevan, S. (2014). An evidential DEMATEL method to identify critical success factors in emergency management. *Applied Soft Computing*, *22*, 504-510.

Lightfoot, H., Baines, T., & Smart, P. (2013). The servitization of manufacturing: A systematic literature review of interdependent trends. *International Journal of Operations & Production Management*, *33*(11-12), 1408-1434.

Lin, Y., Luo, J., Zhou, L., Ma, S., & Zhou, Z. (2011, July). Servitization strategy: Strategic priority, capacity requirement, and organizational feature. In *Proceedings of 2011 IEEE International Conference on Service Operations, Logistics and Informatics* (pp. 191-196). IEEE.

Lin, C. J., & Wu, W. W. (2008). A causal analytical method for group decision-making under fuzzy environment. *Expert Systems with Applications*, *34*(1), 205-213.

Luz Martín-Peña, M., Díaz-Garrido, E., & Sánchez-López, J. M. (2018). The digitalization and servitization of manufacturing: A review on digital business models. *Strategic Change*, *27*(2), 91-99.

Mahmoudi, S., Jalali, A., Ahmadi, M., Abasi, P., & Salari, N. (2019). Identifying critical success factors in Heart Failure Self-Care using fuzzy DEMATEL method. *Applied Soft Computing*, *84*, 105729.

Marjanovic, U., Rakic, S., & Lalic, B. (2019, September). Digital Servitization: The Next "Big Thing" in Manufacturing Industries. In *IFIP International Conference on Advances in Production Management Systems* (pp. 510-517). Springer, Cham.

Marcon, E., Marcon, A., Le Dain, M. A., Ayala, N. F., Frank, A. G., & Matthieu, J. (2019). Barriers for the digitalization of servitization. *Procedia CIRP [recurso eletrônico]. [Amsterdam]*.

Martinez, V., Bastl, M., Kingston, J. and Evans, S. (2010), "Challenges in transforming manufacturing organisations into product-service providers", *Journal of Manufacturing Technology Management*, Vol. 21 No. 4, pp. 449-469.

Michalik, A., Besenfelder, C., & Henke, M. (2019). Servitization of Small-and Medium-Sized Manufacturing Enterprises: Facing Barriers through the Dortmund Management Model. *IFAC-PapersOnLine*, *52*(13), 2326-2331.

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, *56*(3), 1118-1136.

Mont, O. K. (2002). Clarifying the concept of product–service system. *Journal of Cleaner Production*, *10*(3), 237-245.

Neely, A. (2009). Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research*, *1*(2), 103-118.

Neely, A., Benedettini, O., & Visnjic, I. (2011, July). The servitization of manufacturing: Further evidence. In *18th European Operations Management Association Conference* (Vol. 1).

Neely, A. (2013). Servitization in Germany: An international comparison. *Cambridge Service Alliance,* 1-10.

Opresnik, D., & Taisch, M. (2015). The value of big data in servitization. *International journal of production economics*, *165*, 174-184.

Paiola, M., & Gebauer, H. (2020). Internet of things technologies, digital servitization and business model innovation in BtoB manufacturing firms. *Industrial Marketing Management*.

Pal, R. (2016). Extended responsibility through servitization in PSS. *Journal of Fashion Marketing and Management: An International Journal*.

Parida, V., Sjödin, D. R., Lenka, S., & Wincent, J. (2015). Developing global service innovation capabilities: How global manufacturers address the challenges of market heterogeneity. *Research-Technology Management*, *58*(5), 35-44.

Paschou, T., Adrodegari, F., Perona, M., & Saccani, N. (2017). The digital servitization of manufacturing: a literature review and research agenda. In *27th RESER Conference Bilbao [Online]. Available: https://www.researchgate.net/publication/319628925_The_digital_servitization_of_manufacturing_a_literature_review_and_research_agenda [Accessed: 20 April 2018]*.

Rabetino, R., Harmsen, W., Kohtamäki, M., & Sihvonen, J. (2018). Structuring servitization-related research.

Rabetino, R., Kohtamäki, M., & Gebauer, H. (2017). Strategy map of servitization. *International Journal of Production Economics*, *192*, 144-156.

Raddats, C., Kowalkowski, C., Benedettini, O., Burton, J., & Gebauer, H. (2019). Servitization: A contemporary thematic review of four major research streams. *Industrial Marketing Management*, *83*, 207-223.

Ramachandran, S., & Masood, S. (2019). *Aligning Industry 4.0 and Servitization* [Ebook]. Retrieved 23 November 2020, from https://www.infosys.com/about/knowledge-institute/insights/documents/aligning-industry.pdf.

Reddy, S. K., & Reinartz, W. (2017). Digital transformation and value creation: Sea change ahead. *Marketing Intelligence Review*, *9*(1), 10-17.

Rojko, A. (2017). Industry 4.0 concept: background and overview. *International Journal of Interactive Mobile Technologies (iJIM)*, *11*(5), 77-90.

Rudnick, M., Riezebos, J., Powell, D. J., & Hauptvogel, A. (2020). Effective after-sales services through the lean servitization canvas. *International Journal of Lean Six Sigma*.

Rust, R. T., & Huang, M. H. (2014). The service revolution and the transformation of marketing science. *Marketing Science*, *33*(2), 206-221.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. *Boston Consulting Group*, *9*(1), 54-89.

Santamaría, L., Nieto, M. J., & Miles, I. (2012). Service innovation in manufacturing firms: Evidence from Spain. *Technovation*, *32*(2), 144-155.

Schroeder, A., Galera Zarco, C., Baines, T., & Ziaee Bigdeli, A. (2016, May). Barriers to capturing the value of advanced services and digitisation in the road transport industry. In *Spring Servitization Conference SSC2016*.

Schwab, K. (2016, January). The Fourth Industrial Revolution: what it means, how to respond. In *World economic forum* (Vol. 14, No. 01, p. 2016). Crown Business.

Servitization. Sketchbubble.com. (2020). Retrieved 10 October 2020, from https://www.sketchbubble.com/en/presentation-servitization.html.

Shieh, J. I., Wu, H. H., & Huang, K. K. (2010). A DEMATEL method in identifying key success factors of hospital service quality. *Knowledge-Based Systems*, *23*(3), 277-282.

Shrouf, F., Ordieres, J., & Miragliotta, G. (2014, December). Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm. In *2014 IEEE international conference on industrial engineering and engineering management* (pp. 697-701). IEEE.

Silva, L. M., Viagi, A. F., & Giacaglia, G. E. O. (2018). THE SERVITIZATION IN INDUSTRY 4.0, FACING CHALLENGES AND TENDENCIES. *Engineering Research: technical reports*, *9*(3).

Smith, L., Maull, R. and C.L. Ng, I. (2014), "Servitization and operations management: a service dominant-logic approach", *International Journal of Operations & Production Management*, Vol. 34 No. 2, pp. 242-269.

Tabaklar, T., & Yildirim, C. (2020). The Development of Servitization Concept in the Era of Industry 4.0 Through SCM Perspective. In *Handbook of Research on Strategic Fit and Design in Business Ecosystems* (pp. 593-615). IGI Global.

Tether, B., & Bascavusoglu-Moreau, E. (2011). Servitization-the extent of and motivation for service provision amongst UK based manufacturers. *AIM Res. Work. Pap. Ser*.

Thoben, K. D., Wiesner, S., & Wuest, T. (2017). “Industrie 4.0” and smart manufacturing-a review of research issues and application examples. *International journal of automation technology*, *11*(1), 4-16.

Torrecilla-García, J. A., Pardo Ferreira, M. D. C., Martínez Rojas, M., & Rubio Romero, J. C. (2019). Emergent approach of occupational health and safety within the servitization of Industry 4.0. In *13th International Conference on Industrial Engineering and Industrial Management*. Servicio de Publicaciones de la Universidad de Oviedo.

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment*, *13*(4), 246-260.

Turunen, T., & Finne, M. (2014). The organisational environment’s impact on the servitization of manufacturers. *European Management Journal*, *32*(4), 603-615.

Turunen, T., & Neely, A. (2012). Organising servitization: an in-depth case study. *Report. Cambridge Service Alliance*.

Ustundag, A., & Cevikcan, E. (2017). *Industry 4.0: managing the digital transformation*. Springer.

Vandermerwe, S., & Rada, J. (1988). Servitization of business: adding value by adding services. *European Management Journal*, *6*(4), 314-324.

Vendrell-Herrero, F., Bustinza, O. F., Parry, G., & Georgantzis, N. (2017). Servitization, digitization and supply chain interdependency. *Industrial Marketing Management*, *60*, 69-81.

Visnjic, I., & Van Looy, B. (2012). Servitization: Disentangling the impact of service business model innovation on the performance of manufacturing firms. *ESADE Business School Research Paper*, (230).

Visonà, S. (2020). Shaping digital servitization using I4. 0 technologies: two exemplary cases in BtoB manufacturing.

Wang, K., Jiang, Z., Peng, B., & Jing, H. (2020). Servitization of manufacturing in the new ICTs era: A survey on operations management. *Frontiers of Engineering Management*, 1-13.

Wang, W., Lai, K. H., & Shou, Y. (2018). The impact of servitization on firm performance: a meta-analysis. *International Journal of Operations & Production Management*.

Westergren, U. H., & Jonsson, K. (2004). Barriers to the adoption of remote monitoring systems in service processes. In *Service Excellence in Management: Interdisciplinary Contributions, Proceedings of the QUIS 9 Conference* (pp. 539-548). Karlstad University Press, Karlstad.

Wu, W. W. (2008). Choosing knowledge management strategies by using a combined ANP and DEMATEL approach. *Expert Systems with Applications*, *35*(3), 828-835.

Yeh, T. M., & Huang, Y. L. (2014). Factors in determining wind farm location: Integrating GQM, fuzzy DEMATEL, and ANP. *Renewable Energy*, *66*, 159-169.

Zadeh, L. A. (1965). Information and control. *Fuzzy sets*, *8*(3), 338-353.

Zambetti, M., Khan, M. A., Pinto, R., & Wuest, T. (2020). Enabling servitization by retrofitting legacy equipment for Industry 4.0 applications: benefits and barriers for OEMs. *Procedia Manufacturing*, *48*, 1047-1053.

Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. (2020). The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *International Journal of Production Research*, 1-33.

Zhou, Q., Huang, W., & Zhang, Y. (2011). Identifying critical success factors in emergency management using a fuzzy DEMATEL method. *Safety science*, *49*(2), 243-252.

Ziaee Bigdeli, A., Baines, T., Schroeder, A., Brown, S., Musson, E., Guang Shi, V., & Calabrese, A. (2018). Measuring servitization progress and outcome: the case of ‘advanced services’. *Production Planning & Control*, *29*(4), 315-332.