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ASSESSING THE INFLUENCE OF INDUSTRY 4.0 ON BUSINESS
MODELS AND IDENTIFICATION OF THE MOST SIGNIFICANT
DRIVERS TO AND BARRIERS FOR INDUSTRY 4.0
IMPLEMENTATION

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF ATILIM UNIVERSITY

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Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

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ABSTRACT

ASSESSING THE INFLUENCE OF INDUSTRY 4.0 ON BUSINESS MODELS AND IDENTIFICATION OF THE MOST SIGNIFICANT DRIVERS TO AND BARRIERS FOR INDUSTRY 4.0 IMPLEMENTATION

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This thesis aims to identify the key drivers and barriers to the implementation of the Fourth Industrial Revolution (4IR) and their impact on the business model. Specifically, the study focuses on small and medium-sized Enterprises (SMEs) and employs a survey and DEMATEL technique to identify the most significant drivers and barriers, while also conducting a literature review to explore the impact of industry 4.0 on business models. The result of this research highlights four dominant drivers, including agility/ flexibility, decentralized decision-making; data collection in real time; efficiency & quality and increasing the technical skill of employees while the most significant barriers include data confidentiality and safety, resistance, work interruption, and standards problems. This study provides insights into the key factors that SMEs should consider when implementing industry 4.0, enabling them to optimize their business models to remain competitive in the market.

Keywords: Fourth Industrial Revolution, drivers and barriers, business models, small and medium-sized enterprises.

ÖZ

ENDÜSTRİ 4.0'IN İŞ MODELLERİ ÜZERİNDEKİ ETKİSİNİN DEĞERLENDİRİLMESİ VE ENDÜSTRİ 4.0 UYGULAMASINA YÖNELİK EN ÖNEMLİ ETKENLERİN VE ENGELLERİN BELİRLENMESİ

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Bu tez, Dördüncü Sanayi Devrimi'nin (4SR) uygulanmasındaki en önemli etkenleri ve engelleri tespit etmeyi ve bunların iş modeline etkisini belirlemeyi amaçlamaktadır. Özellikle, çalışma küçük ve orta ölçekli işletmelere (KOBİ'ler) odaklanmakta ve en önemli etkenleri ve engelleri belirlemek için bir anket ve DEMATEL tekniğini kullanmaktadır. Ayrıca, iş modelleri üzerinde Endüstri 4.0'ın etkisini araştırmak için bir literatür taraması yapılmaktadır. Bu araştırmanın sonucunda, esneklik/hareketlilik, merkezi olmayan karar alma, gerçek zamanlı veri toplama, verimlilik ve kalite artışı ve çalışanların teknik becerilerinin artırılması gibi dört belirleyici etken ön plana çıkmaktadır. En önemli engeller ise veri gizliliği ve güvenliği, direnç, iş kesintisi ve standart sorunlarıdır. Bu çalışma, KOBİ'lerin Endüstri 4.0'ı uygularken dikkate almaları gereken önemli faktörler konusunda bir perspektif sunarak, iş modellerini optimize etmelerine ve pazarda rekabetçi kalmalarına olanak tanımaktadır.

Anahtar kelimeler: Dördüncü Sanayi Devrimi, etkenler ve engeller, iş modelleri, küçük ve orta ölçekli işletmeler.

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CHAPTER 1

INTRODUCTION

Developments of technologies have allowed the rejection of three major stages that have resulted in a significant growth in production efficiency since the start of the industrial revolution [1]. Industrialization began in the mid-eighteenth to nineteenth centuries with the institution of mechanical manufacturing facilities. In another word, at the late 1700s, water, steam powered device began to be used in production lines. The second industrial revolution began in 1870. It was distinguished by the widespread use of innovative electricity as a power source, allowing large-scale production. Following that, automation has become extensive in manufacturing because of information and communication technologies (ICT) until 1970 and it was third industrial revolution [2]. The fourth industrial revolution (known as Industry 4.0) refers to the current technological evolution in industrial production which is described by digital revolution, robotization, and interconnected production processes. [1]. Industry 4.0 is driven by nine key pillars: cyber-physical systems, the internet of things, autonomous robots, simulation, augmented reality, system integration, additive manufacturing, the cloud, and big data analytics [3].

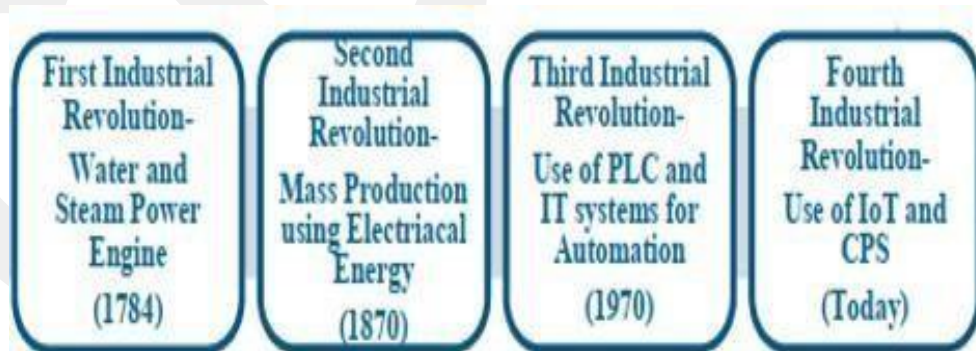


Figure 1 The four different industry revolutions

Motivation: The fourth industrial revolution, known as Industry 4.0, has garnered significant attention from practitioners and academics alike. However, upon reviewing the existing literature, it became evident that there were certain gaps and limitations in the scope of research conducted in this area. The recognition of these neglected areas and the potential for contributing to the existing body of knowledge served as a strong motivation for me to delve deeper into this field and conduct an investigation that addresses these gaps.

Aim: This study aimed to identify the most significant drivers and barriers to implementing Industry 4.0 among small and medium-sized enterprises in Ankara, Turkey. And to identify the influence of industry 4.0 on business model (through literature review).

Research question: The two-research question of this study are RQ 1: what is the influence of industry 4.0 on business models? RQ 2: what is/are the most significant driver(s) to and barrier(s) for implementing industry 4.0 in industrial sectors?

The study comprises five chapters: Introduction, Literature Review, Methodology, Data Analysis (and Results), and Conclusion. Each chapter explores a specific aspect of the research topic. Chapter 2 of the thesis delves into the literature review, exploring various aspects of Industry 4.0. It begins by presenting different definitions of Industry 4.0, followed by an examination of its significant contributions in sectors such as engineering, agriculture, and healthcare. This highlights the revolutionary impact on processes, productivity, and overcoming industry challenges. Additionally, the chapter explores the nine pillars of the fourth industrial revolution, which represent the key technologies and concepts driving Industry 4.0. It then delves into the influence of Industry 4.0 on business models, providing a comprehensive definition and investigating its transformative effects. The chapter further analyzes the specific impacts on business models and concludes by exploring the key drivers and barriers to implementing Industry 4.0. Overall, Chapter 2 provides a comprehensive overview, connecting the definitions, contributions, influence on business models, and drivers and barriers of Industry 4.0. Chapter 3 focuses on the methodologies employed in this study to achieve the research objectives. It provides a detailed explanation of the nine steps followed to reach the final aim of the research. In Chapter 4, the focus shifts to data analysis and the presentation of results. The chapter begins by explaining the four steps of the DEMATEL technique, which was chosen as the primary method for

analyzing the data collected in this study. By elaborating on these steps, the chapter provides a comprehensive understanding of how the DEMATEL technique was applied to the collected data. Following the data analysis, the chapter proceeds to present the results obtained from the application of the DEMATEL technique. These results are then discussed in detail.

Lastly, Chapter 5 presents the conclusion and outlines areas for future work. The chapter summarizes the key findings, recaps the research objectives, and provides answers to the research questions posed earlier in the study.

CHAPTER 2

LITERATURE REVIEW

With the massive digitalization of industries and the integration of all of value chain to the internet, a new industrial revolution emerged which called "fourth industrial revolution (industry 4.0)" [5]. With this new industrial revolution, practitioner and academician got from it a helpful solution for many issues such the traditional agriculture method after world's population increased food demand became a universal issue [6]. This issue highlights the potential solution of transitioning to smart agriculture, also known as agriculture 4.0. As society ages and technological advancements continue to grow, there is an increasing need for improved service performance to meet people's necessities and satisfy their expectations. That is why most developed countries are now implementing Industry 4.0 notions to reduce inefficiencies of medical services [7]. Furthermore, several medical practitioners are starting to turn to technological advances in pandemic period (COVID-19) to improve the quality of patient care they provide, such as mobile apps and remote monitoring [8].

The term Industry 4.0 are defined by several authors in different studies. (Vaidya et al., 2018) Industry 4.0 is described as the latest type of structure and control over all production cycles, with a focus on increasingly personalized customer needs [9]. According to (Mario et al., 2016). The interconnection of industrial activity and technologies that enable communication and information exchange is defined as Industry 4.0. [10]. Industry 4.0 represents the latest paradigm shift in manufacturing, where companies increasingly rely on automation and data sharing to drive efficiency and innovation [11]. According to (Dembirbag et al., 2018) "Digitalization, automation, and interconnected productions are causing an emerging trend in industrial output. It is obvious that "Industry 4.0", the fourth phase of the industrial revolution, will just be a large multi encompassing a wide range of specialties [12].

Furthermore, industries 4.0 can be applied practically in all types of industries: healthcare industries, manufacturing industries, mobile (transporting) industries, and

agriculture. According to Xiaobo Xiang (2021), since the emergence of the fourth industrial revolution, health care technologies have significantly improved the health outcomes of developed countries. [10]. Health innovation refers to the creation of fresh concepts, equipment, and methods in the field of health care [13]. The fourth industrial revolution has had significant impacts on public health. As a result of the new digital revolution, characterized by advances in digitalization, the role of health care technology is becoming more important [14]. Technologies will help us bring better medicines to patient through the fast artificial intelligent.

(AI). Medical devices, biological sensors, and the digitization of healthcare records are all supercharging discovery capabilities at present. With this revolution, we will be able to develop solutions for unmet medical needs that are currently very difficult to address [15].

Agriculture 4.0 involves the integration of various emerging technologies into traditional farming techniques and global agriculture strategies, with the goal of improving and modernizing the agricultural production process from start to finish [16]. Optimizing agricultural output requires the development of innovative strategies that aim to reduce losses and waste throughout the entire value chain of production (Leia et al., 2020). To improve efficiency, traditional agricultural systems that are based on processes must be transformed into more intelligent systems that rely on data and emerging technologies [16]. The table below provides a summary of the contribution of Industry 4.0 on various sectors.

Table 1 The contribution of industry 4.0 in agriculture and healthcare sector.

Industrial sector	Contribution of industry 4.0	Reference
Engineering	Industry 4.0 enhances productivity, efficiency, flexibility, agility, profitability, and customer satisfaction.	[17]
Healthcare	It took a vital role fighting COVID- 19 in pandemic period with new technological advance such as mobile apps and remote monitoring which improve the quality of patient care by medical practitioner. the objective of Health 4.0 is to improve the quality and efficiency of healthcare, optimize costs and resources, and increase effectiveness.	[18] [19]

Agriculture	The digital transformation of agriculture allows for the adoption of modern farming practices such as vertical farming (hydroponics, aquaponics, and aeroponics), which have the potential to address food security issues. Agriculture 4.0 enables the development of innovative strategies in production systems that aim to minimize losses and waste throughout the value chain to maximize agricultural productivity.	[20] [21]
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The manufacturing industry is transitioning from mass production to customized production and is being influenced by nine new technologies. The manufacturing industry is undergoing a transformation driven by nine key technologies, collectively referred to as the pillars of Industry 4.0.

2.2 NINE PILLARS OF THE FOURTH INDUSTRY REVOLUTIONS

The nine pillars of Industry 4.0 are driving the transformation of the manufacturing industry, enabling the creation of smart factories that are more efficient, flexible, and sustainable.

These technologies are also leading to new business models and opportunities for companies to differentiate themselves in a highly competitive market.

1. Big Data and analytics

Big Data involves the analysis of a vast amount of data, which can come in various forms and be generated at a rapid pace. The goal of analyzing this data is to identify problems that have occurred in the past and predict potential issues in the future, as well as to find solutions to prevent these issues from continuing to occur. Through the analysis of this data, industries can gain valuable insights and improve their operations [22].

2. Autonomous Robots

Robots are typically used to perform complex tasks and are now becoming more advanced in their capabilities. They are becoming more self-sufficient, adaptable, and able to work cooperatively with each other and with humans. As they continue to evolve, they will be able to interact with one another, work safely alongside humans, and learn from them. [23].

3. Simulation

Simulation capabilities allow the testing of virtual objects of product and systems

operation before implementing them in real world solution, thereby optimizing the development of technologies. Product design, processes and factory layout can all be virtualized using simulation [24].

4. System Integration

In industrial organization, integration and self-optimization are the main mechanisms at play. The industry 4.0 paradigm is defined by three dimensions of integration: horizontal integration across the entire value creation network, vertical integration, and networked manufacturing.

systems. It also involves end-to-end engineering throughout the product's life cycle [22].

5. Industrial internet of things

As part of the Industrial Internet of Things, most equipment will be equipped with embedded computing and connected using standard technologies. This allows embedded systems to interact with each other and with additional devices as needed. It also enables the diversification of data analysis and decision making, enabling real-time responses as needed. [23].

6. Cyber physical system

The integration of the tangible, service, and virtual realms can improve the accuracy of data required for maximizing efficiency and employing production operations. Cyber physical system is those in which both natural and artificial systems (the physical world) are inextricably linked with computing, communication, and control systems [22].

7. The cloud Additive Manufacturing

Systems that allow computers, systems, software, and devices to be accessed through networks like the internet enable the interaction and integration of diverse components of the fourth industrial revolution through a cloud-based IT platform. To achieve quick response times of milliseconds or less, Industry 4.0 requires organizations to share more data across locations and companies. [22].

8. Additive Manufacturing

Originally used to create prototypes or lower-quality versions of complex parts,

additive manufacturing (also called 3D printing) is now being used for mass production. This technology involves building objects by layering plastic or metal and can help to minimize wastage of material during the fabrication, such as through cutting [24].

9. Augmented reality

Augmented reality technology can assist with a variety of tasks, such as assisting employees in selecting section in a warehouse and providing maintenance guidance on a smart phone. Augmented reality may be employed in industrial settings to offer data in time to laborers to take decision and enhance workflows. In examination phase of a failed system, a practitioner might well obtain guidance on replacing a particular component [24].

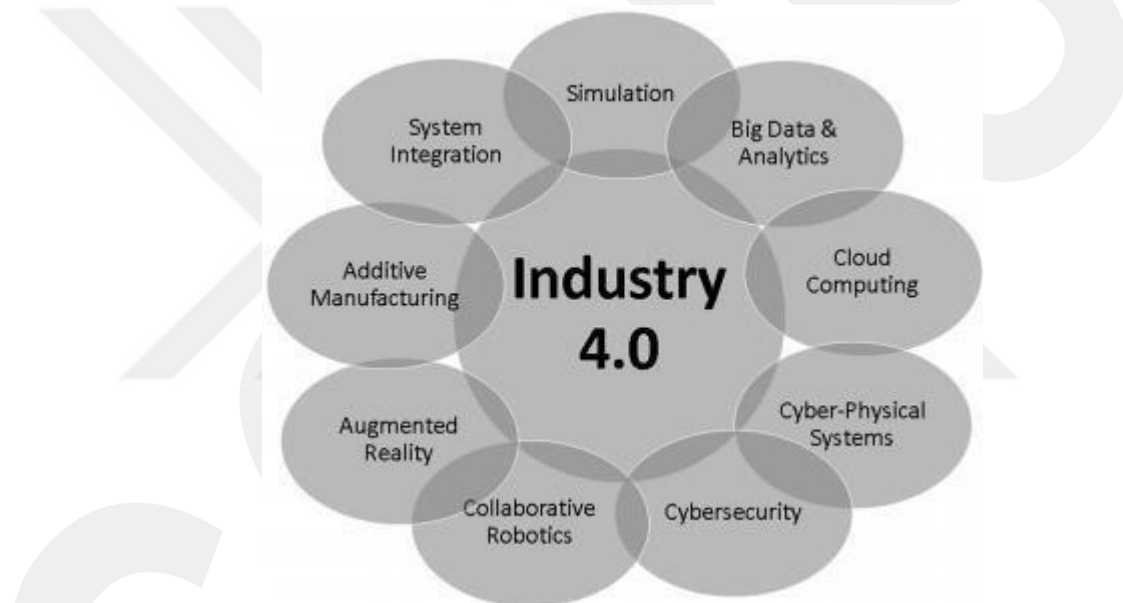


Figure 2 Pillars of industry 4.0 [24]

2.3 THE NECESSARY STEPS TO IMPLEMENT INDUSTRY 4.0.

Since Industry 4.0 is the new industry transformation that drives more competitiveness between competitors and brings such opportunities (flexibility, new assisted technologies, etc.), as a result, it is critical for SMEs to understand how to successfully implement this new revolution to avoid wasting time and capital in the wrong places and ways. According to Optessa(2019) and Carle Roig (2020), the following table presents the four necessary steps to implement Industry 4.0 and their descriptions.

Table 2 Necessary steps for implementation of industry 4.0.

Steps	Description	Reference
Identifications of departure point	Where will you start? Where is actual position?	(Carlo, 2020)
Focus on industry 3.0	Autonomous and information and communication technologies (ICT) were started in Industry 3.0.	(Optessa, 2019)
Plan (Strategy)	“Road map is essential during the journey. “ Strategy or plan is essential when a company Implement new industry revolution.	(Carlo, 2020) (Optessa, 2019)
Start small	Because of the obstacles, it is best to deal with them one at a time.	(Optessa, 2020)

The contribution of industry 4.0, the nine pillars, and the necessary steps to implement industry 4.0 were discovered in the previous section of this study. It's now time to demonstrate the impact of Industry 4.0 on business models. Because SMEs are more likely to face changes in their business models when attempting to implement this new trend. The changes and definitions of business models are provided in the sections that follow.

2.4 BUSINESS MODEL

2.4.1 Definition for business model

Throughout the literature, we learn various interpretations and features of business models. According to (Alexander, 2010), a business model is how businesses produce, convey, and exploit opportunities. Their explanation of a business model was guided by several questions, including what to provide clients, who clients are, and how to conduct business in a durable and beneficial manner [25]. According to (Raphael et al; 2010), the concept of business model is characterized by a sequence of interrelated institutional actions that generate around everyone, physical, and available assets to reach the firm's aims [26]. (Arne, 2010) interprets business models as a methodology of adding value, or just getting profit.

According to (sobol; 2014) business models can come in two forms or frameworks: value models and process models which the value model is concerned with the creation of value, who creates value, and for whom the value is going to be created. The value model assists businesses in determining their placement to maximize actual profit or

drive growth. In contrast, the second one offers an important design of procedures in relation to a company's plan, or obviously gives an instruction on how things must be done for the firm to achieve its goals [27].

2.4.2 Impact of industry 4.0 on business model

This section depicts the impact or influence of Industry 4.0 on the business model by reviewing various articles and displaying their outcomes. This task provides an answer to the first research question, which is: What is the influence of Industry 4.0 on business models? There are two questions beneath it. The first question is, in the literature review, is there any influence or impact that business models earn from Industry 4.0? If so, what are the changes or impacts? These two questions, which fall under the umbrella of the first research question, will be addressed in the following paragraphs. According to Leonard Kainer (2017), employs the nine elements of the business model canvas to reveal business model modifications following the implementation of the industry 4.0 concept in a German manufacturer (see figure 3) [28].

He figured out that all the investigated companies had noticed changes in customer relationships, key resources, and cost structure. These are the elements of the business model that have been most heavily influenced by the fourth industrial revolution in all the companies that took part in his study. Less than 20% of all the companies saw no change in key activities, key partners, or the value proposition business element because of Industry 4.0, which means these last business elements are the second-highest impacted group after implementation of Industry 4.0 (80% of the companies saw changes in these business component). And just 17% of companies saw change in channels business element after industry 4.0 implementation.

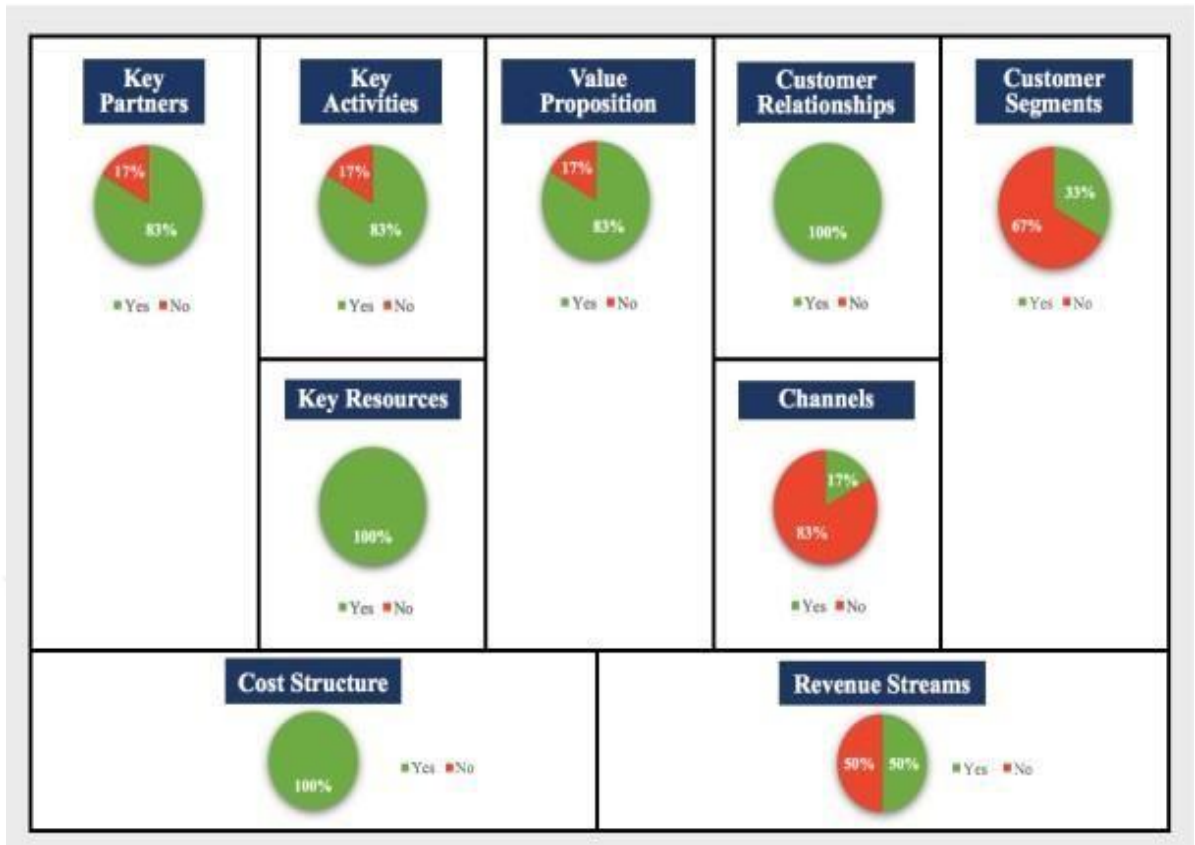


Figure 3 Business model element changes after implementation industry 4.0 [28].

Julian Marius (2018) conducted interviews with 43 skilled individuals from the three largest German industries in his paper. These skilled individuals assigned business model implications by industry 4.0, using or referring to the business model canvas. He discovers that key resources and the value proposition are two of the most impacted components of the business model, while channels are the least impacted. Based on the responses of 43 skilled people who participated in the interview, he established business model building blocks and exemplary changes through Industry 4.0 in his paper. The table 3 below depicts Julian's discovery table depicts business model component and changes brought about by industry 4.0 [28-2].

Table 3 Julian’s discovery table depicts business model component and changes brought about by industry 4.0 [28-2].

<i>Nine business elements (canvas)</i>	<i>Total ratio (%)</i>
<i>Key resources</i>	58.14
<i>Value proposition</i>	53.49
<i>Key partners</i>	48.84
<i>Customer relationships</i>	48.84
<i>Customer segment</i>	41.86
<i>Revenue streams</i>	41.86
<i>Cost structure</i>	37.21
<i>Key activities</i>	23.26
<i>Channels</i>	18.61

Sandra and Sebastian (2022), in their study, did a survey to evaluate the impact of industry 4.0 on the business models of 70 companies in Poland. They display as a result that 70% of companies said or responded that industry 4.0 has had a positive impact on their business models after the implementation. However, 17% of companies said they received a negative impact from industry 4.0 on their business models. Four companies said there was no impact, and five others said they had no idea. The following figure depicts the result of Sandra and Sebastian's study.

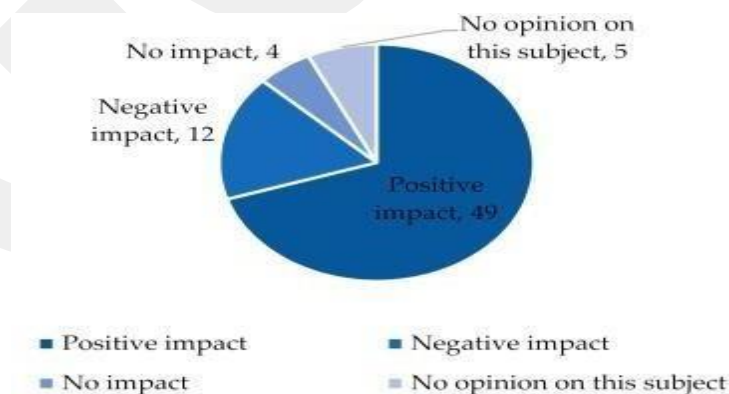


Figure 4 Impact of industry 4.0 on business model (based on Sandra and Sebastian’s (2022) research result).

So, industry 4.0 implementation influences or impacts the business model's components both negatively and positively. Now the next question will be addressed. What are the changes or impacts that Industry 4.0 has on the business model?

The list of changes in business models will be represented according to different papers in table 4. In literature, of course, the author used a different method to find the result. For instance, according to Leonard Kainer (2017), he used a code to structure, reformulate, or summarize in one sentence all the different answers that respondents gave him (all these codes are in Table 3). And Sandra and Sebastian provided a list of some changes to their respondents, asking them to rank them if they noticed such changes after they implemented Industry 4.0. The first three changes that most respondents noticed are: computing on price, product, and service quality (the rest is represented in Table 4). Julian Marius (2018), similarly Kainer, did reformulations about the answers of responders to find the one sentence in which the changes that responders noticed after implementing Industry 4.0 are described. Dorleta et al. (2018), after they analyzed 26 documents, establish a table in which the authors display the change that may face a business model after implementing Industry 4.0.

Table 4 The list of changes in business models according to different papers

Reference	Changes in business models following the implementation of Industry 4.0
Leonard Kainer (2017),	Shifts in customer segmentation, increased customer satisfaction, Customer system insights, Customer loyalty, enhanced forecasting, Cost cutting, improved maintenance service, More adaptability, superior quality, Channel switching, IT expertise, Personnel, raw materials
Julian Marius (2018)	It is necessary to use the most recent equipment. IT skilled personnel are required, as well as retraining current personnel, more flexible and personalized production, large investment required Increased productivity results in cost savings.
Sandra and Sebastian (2022),	Rivalry for prices, performance of goods and services, interaction with consumer instruments, product variety, and new business areas
Dorleta et al, 2018	Interoperability, virtualization, decentralization of decision making, real-time capability, service orientation, and modularity.

The preceding section of this study highlighted the influence of Industry 4.0 on business models and demonstrated the potential benefits of integrating Industry 4.0

technologies, such as increased productivity, enhanced quality, and cost reduction. However, realizing these benefits requires a deep understanding of the most significant drivers and barriers to implementing Industry 4.0. As such, this next section will delve into a comprehensive analysis of the key drivers and barriers to Industry 4.0 implementation, which is essential for businesses to successfully leverage the advantages offered by Industry 4.0 technologies and overcome the challenges that come with their implementation.

2.5 EXPLORING THE KEY DRIVERS AND BARRIERS TO IMPLEMENTING INDUSTRY 4.0

Industry 4.0 is a transformational approach to manufacturing and industrial processes that leverages cutting-edge technologies such as the Internet of Things (IoT), artificial intelligence (AI), and robotics to create more efficient, flexible, and sustainable operations. However, the implementation of Industry 4.0 is not without challenges. In this study, we examine the drivers and barriers to the implementation of Industry 4.0, focusing on the key factors that encourage or hinder its adoption. The drivers are the factors that motivate organizations to adopt Industry

4.0 technologies, while the barriers are the factors that impede or slow down their adoption. Understanding both drivers and barriers is essential for organizations to successfully navigate the complex landscape of Industry 4.0 and realize its full potential. In the following tables, we present the key drivers and barriers to Industry 4.0 implementation, based on a review of existing literature and industry reports.

Table 5 List of drivers for industry 4.0 implementation

Drivers of industry 4.0	Brief Description	Reference
Profitability /increasing productivity	Industry 4.0 implementation can provide ability to examine new methods/approaches for growing the company's revenue and profit.	[29]
Reduction of cost	The implementation of Industry 4.0 can lead to significant cost savings.	[30]
innovations	Implementation of industrial 4.0 approaches can help a company think creatively and generate new ideas for process/product innovation.	[31]
Applying industry 4.0 technologies	Using information and communication technology to computerize data, utilizing new software technologies to model, simulate, and virtualize, Creation of cyber-physical systems for tracking and controlling physical processes. the development of intelligent systems and assistance through the use of augmented reality	[32]

Decision- making is decentralized	Decentralized decision-making is critical in an organization to reduce disruptions or delay, enhance the process of business development, and empower creative solutions.	[33] [31]
Agility/ flexibility	Agility refers to a firm's capability to make changes quickly and efficiently. Operations within an industry 4.0 must be agile, reliable, and flexible in order to react to shifts in resource requirements, supply, and prices.	[34]
Data collection in real time	I4.0 technological advances deliver real-time access to the most up-to-date and credible data, allowing for the recognition of obstacles and weaknesses, allowing for more decision making.	[32]
Efficiency & quality	Industry 4.0 includes advanced analytics, which aid in preventing obstacles, reducing equipment failure, and generating consistency across the full supply network, consequently enhancing efficiency levels.	[33]
Government policies/legislations	Government policies that support and participate in the digital business system by offering and facilitating the necessary I4.0 infrastructure are a driving factor of I4.0 implementation.	[35]
Increasing the technical skill of employees	Improve staff competence so that they can deal with new technology.	[32]
Diminished boring and repetitive job	Automated and intelligent facilities handle routine and boring job.	[31]
pollution in the environment decreased	Some of the technologies and practices associated with Industry 4.0, such as the use of renewable energy sources and more efficient production processes, may help to reduce pollution and environmental impact.	[36]
The firm's dimensions	Refers to the size and scope of a business, businesses of various sizes and industries may benefit from the adoption of Industry 4.0 technologies.	[33]
Transparency	In the context of Industry 4.0, transparency refers to the ability of organizations to collect and share data across various stages of the production process, enabling greater collaboration and visibility into operations.	[37]
The influence of stakeholders (pressure)	Government agencies, service providers, and customers who are stakeholders can all influence a company's adoption of Industry 4.0.	[34]

Table 6 List of barriers for industry 4.0 implementation.

Barrier of industry 4.0	Brief description	Reference
insufficient budget and resources	The transition to Industry 4.0 has economic costs that companies could not be capable of bearing.	[38]
Insufficient employee skills	Insufficient skills and knowledge to shift from old system to new system.	[32]
Government assistance is absent.	Government policy measures to guide Industry 4.0 implementation are lacking.	[39]

Insufficient manager skills	Refer to a lack of knowledge and understanding among managers of the potential benefits and risks associated with Industry 4.0 technologies. This can lead to a reluctance to invest in new technologies or a lack of vision for how to integrate new technologies into existing processes.	[32]
Resistance	Some representatives of upper executives are opposed to the implementation of industry 4.0.	[40]
Infrastructure Deficit	Define to a lack of investment in physical and digital infrastructure necessary to support the adoption of Industry 4.0 technologies.	[30]
insufficient technological capability	Insufficient technical knowledge and ability and rigid technologies inhibit industry 4.0 implementation.	[41]
Problems with data confidentiality and safety	When implementing Industry 4.0, security and confidentiality concerns must be addressed.	[40]
standards problems	Refer to challenges associated with the lack of standardization in products, processes, and systems used in various industries.	[42]
Current business models are seriously damaged	Damaged business models refer to challenges faced by companies due to changes in market conditions, consumer behavior, technological advancements, and other factors.	[31]
Poor digital perception	Refers to a lack of understanding or awareness of the potential benefits and risks associated with digital technologies. This can lead to a reluctance to adopt new technologies or a lack of investment in digital infrastructure.	[43]
insufficient training	Define to a lack of investment in training programs that would enable workers to acquire the skills necessary to work with new technologies.	[33]
Insufficient R&D programs	Inadequate R&D programs are defined as an absence of investment in research and development activities that would allow businesses to come up with new items based on the latest technology.	
Concerns about the law.	Refer to the legal and regulatory challenges associated with the adoption of new technologies.	

The following tables have been curated to include the most cited drivers and barriers to the implementation of industry 4.0, based on extensive review of relevant literature. These tables will be included in the questionnaire and distributed among the participants to elicit their perspectives and insights on the topic.

Table 7 List of drivers of questionnaire paper.

Drivers of industry 4.0				
Profitability / increasing productivity	Reduction of cost	innovations	Applying industry 4.0 technologies	Decision-making is decentralized.
Agility/ flexibility	Data collection in real time	Efficiency & quality	Government policies/ legislations	Increasing the technical skill of employees.

Table 8 List of barriers of questionnaire paper.

Barriers		
insufficient budget and resources	Insufficient employee skills	Government assistance is absent.
Resistance	insufficient technological capability	Problems with data confidentiality and safety
standards problems	Insufficient manager skills	

CHAPTER 3

METHODOLOGY

As it is illustrated in Figure 5, this study progressed through nine consecutive phases, each aimed at addressing the research questions identified in the literature review.

In Phase 3.1, a comprehensive literature review was conducted to gather general information about Industry 4.0. This step included a discussion of the brief history of different industrial revolutions, an exploration of the new technologies introduced by Industry 4.0, and an examination of the influence of Industry 4.0 on business models. Additionally, tables 3 and 4 were presented, listing the drivers and barriers to implementing Industry 4.0.

During the gap analysis task in Phase 3.2, multiple gaps were identified in the existing literature. Two critical gaps emerged as significant areas that had been overlooked. Firstly, the study observed a lack of extensive research on the most crucial factor contributing to the success of Industry 4.0 implementation. Secondly, the impact of Industry 4.0 on business models had been inadequately addressed.

Based on the gap analysis, in Phase 3.3, two research questions were formulated. Research Question 1 focused on exploring the influence of Industry 4.0 on business models, while Research Question 2 aimed to identify the most significant drivers and barriers to implementing Industry 4.0 in industrial sectors.

Phase 3.4 involved selecting a survey methodology. The survey questionnaire was chosen as it provides a systematic approach to collecting data from a sample of people. It ensures standardized data collection, minimizing bias and increasing the reliability of the results. Additionally, survey questionnaires generate structured data that can be easily analyzed using statistical or mathematical methods.

The survey questionnaire, presented in Phase 3.5, consisted of four sections. The first section provided an introduction to Industry 4.0 and instructions on completing the questionnaire. The second and third sections included tables presenting the drivers and barriers to implementing Industry 4.0. The final section allowed participants to provide optional personnel information while assuring confidentiality.

In Phase 3.6, the questionnaire was initially distributed via email. However, due to

language barriers and other reasons, no responses were received despite follow-up emails. As a result, the decision was made to distribute the questionnaire face-to-face to non-responsive participants. Table 9 summarized information about the sending case, including the number of participants, their roles, the industry types, and the location and size of the companies involved.

Table 9 Information about a sending case summarized.

Number of participants	18
Participants type	Practitioner
Participant title	Electric, mechatronic, software, mechanic engineers. Some technician and some manager.
Industry type	Electric, automation, technology invention, 3D printing, hydraulic, health equipment maintenance, software developer.
Location & size of companies	Ankara Small and medium enterprise (SME)

In the phase 3.7, the DEMATEL (Decision-Making Trial and Evaluation Laboratory) technique is a valuable tool for understanding complex relationships and decision-making processes. According to Mardani (2017), DEMATEL aids in identifying the relationships and dependencies between various factors or variables in a system, allowing decision-makers to better understand the underlying causes of problems [45]. According to Yu (2019), DEMATEL allows for the identification of critical variables or contributing factors that have a significant impact on the system, allowing efforts to be focused on the most critical areas [46]. Additionally, the simplicity of the DEMATEL technique played a crucial role in its selection. Compared to other complex and resource-intensive methods, the DEMATEL technique offered a straightforward and efficient approach to analyze the collected data. Its mathematical calculations and visual representation provided a clear and concise understanding of the relationships among the identified drivers and barriers. This simplicity not only made the analysis process more accessible but also enhanced the overall interpretability of the findings.

Because of these factors, the DEMATEL technique was chosen as an appropriate method of analysis for this study. Because this study seeks to identify the critical factors

that will have a significant impact on the business model following the implementation of Industry 4.0, as well as the interdependence of drivers and barriers.



Figure 5 Research framework

CHAPTER 4

DATA ANALYSIS (DEMATEL TECHNIQUE)

In terms of methodology, a questionnaire was sent to practitioners to fill out based on their skill level. The data collection task was completed once we had received all their feedback. This time, we will do data analysis using the DEMATEL technique. Since the most significant drivers and barriers are wanted, the DEMATEL technique is the best one we can find. The decision-making trial and evaluation laboratory (DEMATEL) is considered an effective method for the identification of cause-and-effect chain components of a complex system.

It deals with evaluating interdependent relationships among factors and finding the critical ones through a visual structural model. The most important property of the DEMATEL method used in the multi-criteria decision-making field is its ability to construct interrelationships between criteria.

There are four steps in the DEMATEL method:

✓ Calculate the average matrix:

In this step, the average matrix is calculated by finding the average value of each element in the initial direct influence matrix. The initial direct influence matrix represents the direct influence of each element on every other element in the system. The average matrix provides a measure of the overall influence of each element.

✓ Calculate the normalized initial direct influence matrix:

In this step, the normalized initial direct influence matrix is calculated by dividing each element in the initial direct influence matrix by the sum of the corresponding column. This normalization process ensures that the values in the matrix represent the relative influence of each element.

✓ Derive the total relation matrix:

In this step, the total relation matrix is derived by multiplying the average matrix by the normalized initial direct influence matrix. This matrix represents the total influence of each element on every other element in the system.

✓ Set a threshold value and obtain the impact-relations map.

In this final step, a threshold value is set by calculating the average of the total relation matrix to determine the significant relationships in the total relation matrix. Elements with values above the threshold are considered to have a significant impact on other elements.

First, we will analyze data on the driver, followed by data on the barrier.

**4.1.1 Analysis of the driver's data:
Step 1: Calculate the average matrix.**

Table 10 The average matrix of drivers

	Profitability / increasing productivity	Reduction of cost	Innovations	Applying industry 4.0 technologies Innovation	Decision-making is decentralized	Agility/ flexibility	Data collection in real time	Efficiency & quality	Government policies/ legislations	Increasing the technical skill of employees
Profitability / increasing productivity	0	6,111	5,622	6,284	3,741	5,889	6,841	5,681	4,000	5,457
Reduction of cost	0,220	0	5,400	5,062	4,963	5,407	5,619	5,236	4,148	5,136
Innovations	0,571	0,538	0	5,951	4,792	4,795	5,240	5,889	4,622	5,173
Applying industry 4.0 technologies Innovation	0,694	0,747	0,744	0	5,908	5,619	5,844	5,240	3,952	4,741
Decision-making is decentralized	0,553	0,376	1,116	0,807	0	5,728	5,508	4,911	3,951	4,733
Agility/ flexibility	0,235	0,427	0,787	0,684	0,714	0	4,794	6,000	4,173	5,111
Data collection in real time	0,527	0,640	0,984	0,493	0,644	1,000	0	7,556	3,460	5,889
Efficiency & quality	1,154	1,101	0,265	1,022	0,738	0,198	0,146	0	4,063	5,351
Government policies/ legislations	0,344	0,649	0,670	0,743	0,852	0,881	1,189	0,779	0	4,778
Increasing the technical	1,213	0,945	0,771	0,515	0,670	0,298	0,269	1,016	0,381	0

skill of employees										
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Step 2: Calculate the normalized initial direct influence matrix.

To obtain the normalized matrix, the sum of each row (not column) is calculated, and the highest value is selected. In this study, the resulting highest value was 49,626. This value is then used to divide the content of the average matrix in the next step.

Table 11 Shows the total or sum of each line.

49,626	41,192	37,570	33,489	27,685	22,925	21,193	14,038	10,885	6,079
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To find the normalized matrix, we will divide each value in the average matrix by the highest value that we found in the previous step. In this case, the normalized matrix is presented in the following table.

Table 12 The normalized initial direct-influence matrix

0	0,123	0,113	0,127	0,075	0,119	0,138	0,114	0,081	0,110
0,004	0	0,109	0,102	0,100	0,109	0,113	0,106	0,084	0,103
0,012	0,011	0	0,120	0,097	0,097	0,106	0,119	0,093	0,104
0,014	0,015	0,015	0	0,119	0,113	0,118	0,106	0,080	0,096
0,011	0,008	0,022	0,016	0	0,115	0,111	0,099	0,080	0,095
0,005	0,009	0,016	0,014	0,014	0	0,097	0,121	0,084	0,103
0,011	0,013	0,020	0,010	0,013	0,020	0	0,152	0,070	0,119
0,023	0,022	0,005	0,021	0,015	0,004	0,003	0	0,082	0,108
0,007	0,013	0,014	0,015	0,017	0,018	0,024	0,016	0	0,096
0,024	0,019	0,016	0,010	0,013	0,006	0,005	0,020	0,008	0

Step 3: Derive the total relation matrix.

To find the total relation matrix, we must multiply the normalized matrix and the inverse of the subtraction matrix (the identity and normalized matrix). In this case, we already calculated the normalized matrix. And the inverse of the subtraction matrix (the identity and normalized matrix) will be calculated in this step. To calculate the inverse of a normalized matrix, we must first build the identity matrix of a 10 by 10 matrix. Then we subtracted the identity matrix from the normalized matrix ($I - Y$). Once we

have done the subtraction matrix, we will calculate the inverse of the normalized matrix. The identity matrix, subtraction matrix, and inverse matrix are shown in the following tables: 13, 14, and 15.

Table 13 The identity matrix of 10 by 10

1	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	1

Table 14 The subtraction of identity matrix and normalized matrix (1-Y).

1	-	-	-	-	-	-	-	-	-
0,123	1	0,113	0,127	0,075	0,119	0,138	0,114	0,081	0,110
-	0,004	-	-	-	-	-	-	-	-
0,012	0,011	1	0,102	0,100	0,109	0,113	0,106	0,084	0,103
-	-	-	1	-	-	-	-	-	-
0,014	0,015	0,015	0,120	0,097	0,097	0,106	0,119	0,093	0,104
-	-	-	-	1	-	-	-	-	-
0,011	0,008	0,022	0,119	0,113	0,118	0,106	0,080	0,096	-
-	-	-	-	-	1	-	-	-	-
0,005	0,009	0,016	0,016	0,014	0,014	0,097	0,121	0,084	0,103
-	-	-	-	-	-	1	-	-	-
0,011	0,013	0,020	0,010	0,013	0,020	0,152	0,070	0,119	-
-	-	-	-	-	-	-	1	-	-
0,023	0,022	0,005	0,021	0,015	0,004	0,003	0,082	0,108	-
-	-	-	-	-	-	-	-	1	-
0,007	0,013	0,014	0,015	0,017	0,018	0,024	0,016	0,096	-
-	-	-	-	-	-	-	-	-	1
0,024	0,019	0,016	0,010	0,013	0,006	0,005	0,020	0,008	-

Table 15 The inverse of the subtraction of identity matrix and normalized matrix.

1,0	0,150	0,154	0,182	0,1	0,20	0,238	0,254	0,1	0,270
24				45	1			92	

0,0 24	1,023	0,133	0,139	0,1 48	0,16 9	0,188	0,212	0,1 69	0,229
0,0 29	0,032	1,024	0,145	0,1 35	0,14 6	0,168	0,207	0,1 65	0,213
0,0 29	0,034	0,037	1,026	0,1 43	0,15 1	0,168	0,184	0,1 43	0,191
0,0 23	0,023	0,039	0,037	1,0 23	0,13 8	0,146	0,159	0,1 28	0,171
0,0 16	0,021	0,029	0,030	0,0 32	1,02 0	0,118	0,160	0,1 19	0,161
0,0 21	0,026	0,032	0,027	0,0 31	0,03 9	1,024	0,181	0,1 02	0,169
0,0 30	0,032	0,018	0,034	0,0 31	0,02 3	0,025	1,027	0,1 01	0,140
0,0 13	0,020	0,022	0,025	0,0 29	0,03 2	0,041	0,040	1,0 19	0,121
0,0 27	0,025	0,024	0,022	0,0 25	0,02 1	0,023	0,041	0,0 25	1,024

After all the calculations of the inverse of the subtraction matrix are done, we can now calculate the total relation matrix. And it is presented in the following table 16.

Table 16 T matrices (the multiplication of Y matrices and inverse of Y matrices (Y-1)).

0,02 4	0,15 0	0,15 4	0,18 2	0,14 5	0,20 1	0,23 8	0,25 4	0,19 2	0,27 0
0,02 4	0,02 3	0,13 3	0,13 9	0,14 8	0,16 9	0,18 8	0,21 2	0,16 9	0,22 9
0,02 9	0,03 2	0,02 4	0,14 5	0,13 5	0,14 6	0,16 8	0,20 7	0,16 5	0,21 3
0,02 9	0,03 4	0,03 7	0,02 6	0,14 3	0,15 1	0,16 8	0,18 4	0,14 3	0,19 1
0,02 3	0,02 3	0,03 9	0,03 7	0,02 3	0,13 8	0,14 6	0,15 9	0,12 8	0,17 1
0,01 6	0,02 1	0,02 9	0,03 0	0,03 2	0,02 0	0,11 8	0,16 0	0,11 9	0,16 1
0,02 1	0,02 6	0,03 2	0,02 7	0,03 1	0,03 9	0,02 4	0,18 1	0,10 2	0,16 9
0,03 0	0,03 2	0,01 8	0,03 4	0,03 1	0,02 3	0,02 5	0,02 7	0,10 1	0,14 0
0,01 3	0,02 0	0,02 2	0,02 5	0,02 9	0,03 2	0,04 1	0,04 0	0,01 9	0,12 1
0,02 7	0,02 5	0,02 4	0,02 2	0,02 5	0,02 1	0,02 3	0,04 1	0,02 5	0,02 4

We can now calculate the Ri and Ci after we have finished calculating the total relation matrix. Ri is the sum of each line. Ci is the sum of each column. This calculation is presented in the following table 17.

Table 17 The calculation of the Ri & and Ci.

Ri	1,810	1,433	1,264	1,105	0,888	0,706	0,652	0,461	0,360	0,257
Ci	0,236	0,385	0,512	0,667	0,742	0,941	1,138	1,465	1,162	1,690

Then, we calculate the addition and subtraction of Ri and Ci. The result of this calculation allows us to find the influencers and receivers of influence among drivers. And the most significant drivers will be figured out. In another word, the cause-and-effect groups will be found. And it will be mentioned in the results part of this study. The calculation of the addition and subtraction of Ri and Ci is presented in the following table.

Table 18 Addition and subtraction of Ri and Ci.

Ri+Ci	2,047	1,819	1,776	1,772	1,630	1,647	1,790	1,926	1,522	1,947
Ri-Ci	1,574	1,048	0,752	0,439	0,146	-0,235	-0,485	-1,003	-0,803	-1,433

Step 4: Set a threshold value and obtain impact-relations map.

In this step, we are going to calculate the average of the total relations matrix, which is the alpha value. In our study, we have calculated the alpha value, which is the average of the total relation matrix. This value plays a crucial role in determining the cause-and-effect groups. By comparing the content value in the T matrices with the alpha value, we can identify the factors that belong to the effect group. Specifically, any column in the T matrices that has a content value greater than the alpha value will be categorized as belonging to the effect group. For our study, we have found that the alpha value is 0.089.

The values that are highlighted in the table 19 are those that are greater than the alpha value.

0,024	0,150	0,154	0,182	0,145	0,201	0,238	0,254	0,192	0,270
0,024	0,023	0,133	0,139	0,148	0,169	0,188	0,212	0,169	0,229
0,029	0,032	0,024	0,145	0,135	0,146	0,168	0,207	0,165	0,213
0,029	0,034	0,037	0,026	0,143	0,151	0,168	0,184	0,143	0,191
0,023	0,023	0,039	0,037	0,023	0,138	0,146	0,159	0,128	0,171

0,016	0,021	0,029	0,030	0,032	0,020	0,118	0,160	0,119	0,161
0,021	0,026	0,032	0,027	0,031	0,039	0,024	0,181	0,102	0,169
0,030	0,032	0,018	0,034	0,031	0,023	0,025	0,027	0,101	0,140
0,013	0,020	0,022	0,025	0,029	0,032	0,041	0,040	0,019	0,121
0,027	0,025	0,024	0,022	0,025	0,021	0,023	0,041	0,025	0,024

Table 19 T matrices (the multiplication of Y matrices and inverse of Y matrices (Y⁻¹)).

4.1.1 Analysis of the barrier's data:

Step 1: Calculate the average matrix.

Table 20 The average matrix of barriers.

	insufficient budget and resources	Insufficient employee skills	Government assistance is absent.	Insufficient manager skills	Resistance	Current work Will be Interrupted	Problems with confidentiality and safety	standards problems
insufficient budget and resources.	0	5,78	5,40	5,62	5,19	5,51	3,84	4,81
Insufficient employee skills.	0,31	0	4,62	5,64	5,78	6,19	5,02	6,06
Government assistance is absent.	0,63	0,80	0	4,35	4,96	4,70	5,52	5,63
Insufficient manager skills.	0,73	1,30	1,21	0	6,29	6,62	6,40	5,46
Resistance.	0,40	0,20	0,55	0,55	0	5,40	4,95	5,29
Current work Will be Interrupted.	0,84	0,41	0,71	0,46	0,50	0	4,07	4,80
Problems with data confidentiality and Safety.	0,74	0,92	0,36	0,54	0,70	0,63	0	5,41
standards problems.	0,77	0,57	0,46	1,01	0,55	1,00	0,43	0

Step 2: Calculate the normalized initial direct influence matrix.

To obtain the normalized matrix, the sum of each row (not column) is calculated, and the highest value is selected. In this study, the resulting highest value was 36.135. This

value is then used to divide the content of the average matrix in the next step.

Table 21 Shows the total or sum of each line.

36,135	33,608	26,570	27,999	17,345	11,788	9,286	4,786
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To find the normalized matrix, we will divide each value the average matrix the highest value that we have found the previous step. In this case the normalized matrix is presented in the following table 22.

Table 22 The normalized initial direct-influence matrix

0	0,160	0,149	0,155	0,143	0,152	0,106	0,133
0,009	0	0,128	0,156	0,160	0,171	0,139	0,168
0,017	0,022	0	0,120	0,137	0,130	0,153	0,156
0,020	0,036	0,033	0	0,174	0,183	0,177	0,151
0,011	0,006	0,015	0,015	0	0,149	0,137	0,146
0,023	0,011	0,020	0,013	0,014	0	0,113	0,133
0,020	0,025	0,010	0,015	0,019	0,017	0	0,150
0,021	0,016	0,013	0,028	0,015	0,028	0,012	0

Step 3: Derive the total relation matrix.

To find the total relation matrix, we must multiply the normalized matrix and the inverse of the subtraction matrix (the identity and normalized matrix). In this case, we already calculated the normalized matrix. And the inverse of the subtraction matrix (the identity and normalized matrix) will be calculated in this step.

To calculate the inverse of a normalized matrix, we have to first build the identity matrix of a 8 by 8 matrix. Then we subtracted the identity matrix from the normalized matrix ($I - Y$). Once we have done the subtraction matrix, we will calculate the inverse of the normalized matrix. The subtraction matrix, and inverse matrix are shown in the following tables: 23, and 24.

Table 23 The subtraction of identity matrix and normalized matrix ($1 - Y$).

1	-0,160	-0,149	-0,155	-0,143	-0,152	-0,106	-0,133
-0,009	1	-0,128	-0,156	-0,160	-0,171	-0,139	-0,168
-0,017	-0,022	1	-0,120	-0,137	-0,130	-0,153	-0,156

-0,020	-0,036	-0,033	1	-0,174	-0,183	-0,177	-0,151
-0,011	-0,006	-0,015	-0,015	1	-0,149	-0,137	-0,146
-0,023	-0,011	-0,020	-0,013	-0,014	1	-0,113	-0,133
-0,020	-0,025	-0,010	-0,015	-0,019	-0,017	1	-0,150
-0,021	-0,016	-0,013	-0,028	-0,015	-0,028	-0,012	1

Table 24 The inverse of the subtraction of identity matrix and normalized matrix.

1,034	0,196	0,205	0,239	0,265	0,316	0,287	0,362
0,039	1,035	0,162	0,208	0,244	0,293	0,280	0,352
0,040	0,049	1,031	0,156	0,194	0,219	0,251	0,293
0,043	0,061	0,064	1,043	0,219	0,262	0,270	0,291
0,026	0,022	0,032	0,038	1,027	0,181	0,181	0,219
0,033	0,026	0,034	0,034	0,039	1,033	0,142	0,183
0,028	0,036	0,024	0,035	0,043	0,049	1,031	0,186
0,026	0,024	0,024	0,041	0,035	0,053	0,040	1,036

After all the calculations of the inverse of the subtraction matrix are done, we can now calculate the total relation matrix. And it is presented in the following table 23.

Table 25 T matrices (the multiplication of Y matrices and inverse of Y matrices (Y-1)).

0,034	0,196	0,205	0,239	0,265	0,316	0,287	0,362
0,039	0,035	0,162	0,208	0,244	0,293	0,280	0,352
0,040	0,049	0,031	0,156	0,194	0,219	0,251	0,293
0,043	0,061	0,064	0,043	0,219	0,262	0,270	0,291
0,026	0,022	0,032	0,038	0,027	0,181	0,181	0,219
0,033	0,026	0,034	0,034	0,039	0,033	0,142	0,183
0,028	0,036	0,024	0,035	0,043	0,049	0,031	0,186
0,026	0,024	0,024	0,041	0,035	0,053	0,040	0,036

We can now calculate the Ri and Ci after we have finished calculating the total relation matrix. Ri is the sum of each line. Ci is the sum of each column. This calculation is presented in the following table 26.

Table 26 The calculation of the Ri & and Ci.

Ri	1,904	1,613	1,232	1,254	0,727	0,525	0,433	0,280
Ci	0,268	0,450	0,575	0,794	1,068	1,407	1,483	1,923

Then, we calculate the addition and subtraction of Ri and Ci. The result of this calculation allows us to find the influencers and receivers of influence among drivers. And the most significant drivers will be figured out. In another word, the cause-and-effect groups will be found. And it will be mentioned in the results part of this study.

The calculation of the addition and subtraction of Ri and Ci is presented in the following table.

Table 27 Addition and subtraction of Ri and Ci.

Ri+Ci	2,172	2,063	1,807	2,048	1,794	1,932	1,916	1,916
Ri-Ci	1,637	1,163	0,657	0,460	-0,341	-0,883	-1,051	-1,643

Step 4: Set a threshold value and obtain the impact-relations map.

In this step, we are going to calculate the average of the total relations matrix, which is the alphavalue. In our study, we have calculated the alpha value, which is the average of the total relationmatrix. This value plays a crucial role in determining the cause-and-effect groups. By comparingthe content value in the T matrices with the alpha value, we can identify the factors that belongto the effect group. Specifically, any column in the T matrices that has a content value greater than the alpha value will be categorized as belonging to the effect group. For our study, we havefound that the alpha value is 0.089.

The values that are highlighted in the table 28 are those that are greater than the alpha value.

Table 28 T matrices (the multiplication of Y matrices and inverse of Y matrices (Y-1).

0,024	0,150	0,154	0,182	0,145	0,201	0,238	0,254
0,024	0,023	0,133	0,139	0,148	0,169	0,188	0,212
0,029	0,032	0,024	0,145	0,135	0,146	0,168	0,207
0,029	0,034	0,037	0,026	0,143	0,151	0,168	0,184
0,023	0,023	0,039	0,037	0,023	0,138	0,146	0,159
0,016	0,021	0,029	0,030	0,032	0,020	0,118	0,160
0,021	0,026	0,032	0,027	0,031	0,039	0,024	0,181
0,030	0,032	0,018	0,034	0,031	0,023	0,025	0,027

CHAPTER 5

RESULTS

The fourth step of data analysis in the previous part, we calculated the alpha value and compared it to the value of the T matrix. The effect group is the column with more content values than alpha values. In another word, these columns are the most significant drivers and barriers among the others. And the columns that have no content value that is greater than the alpha value are in the cause group. In this case, the causes are profitability, cost reduction, applying Industry 4.0 technologies, decentralized decision making, and innovation.

These drivers are those who influence the effect group. Also known as a dispatcher or influencer. And the effect groups are Agility flexibility, Data collection in real time, Government policies/legislation, Efficiency & quality, increasing the skill of employees. These drivers, which were mentioned above (effect group ones) are the most significant drivers to implement Industry 4.0 among others. These drivers are the receivers; they receive or get influence from the cause group (dispatcher). As a result, a cause-and-effect relationship diagram of drivers for Industry 4.0 implementation is constructed and presented in Figures 6.

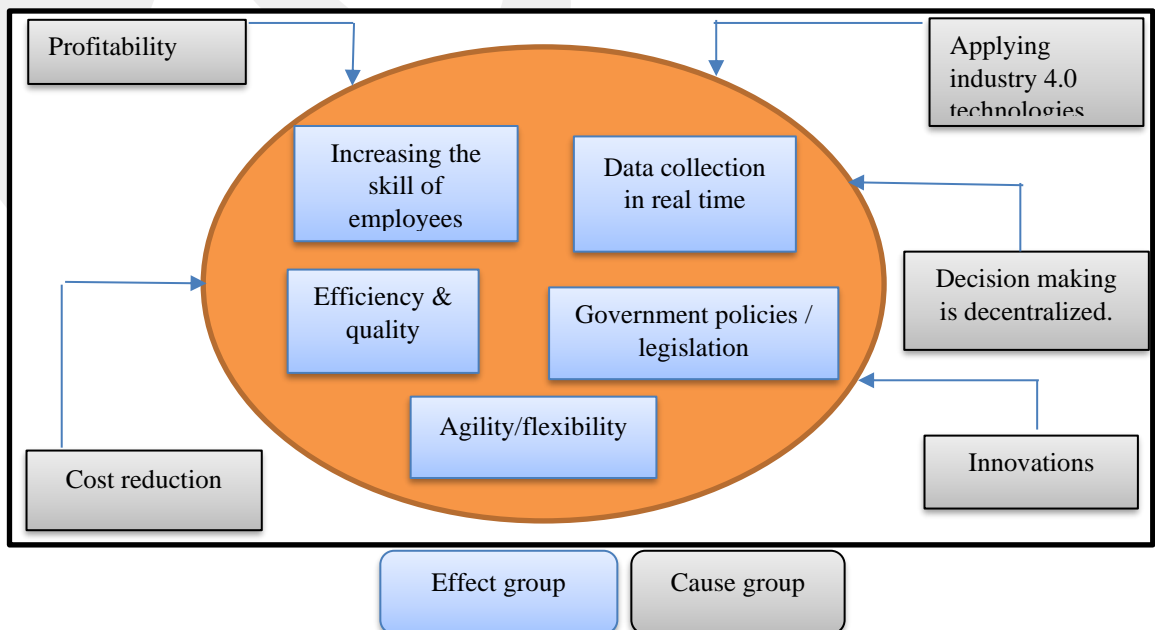


Figure 6 Cause-and-effect relationship diagram of drivers

Same thing for drivers this study identified the cause-and-effect groups of barriers. The causes are insufficient budget and resources, insufficient employee and manager skills, and a lack of government assistance. These barriers are influencer barriers. Also known as a dispatcher. They influence the effect groups. The effect groups are:

- Resistance
- Current work will be interrupted.
- Problems with data confidentiality and safety
- Standards problem

These four barriers are the receivers of the cause group's influence. And they are the most significant barriers that need to be considered when a company tries to implement Industry 4.0. As a result, a cause-and-effect relationship diagram of drivers and barriers to Industry 4.0 implementation is constructed and presented in Figures 7.

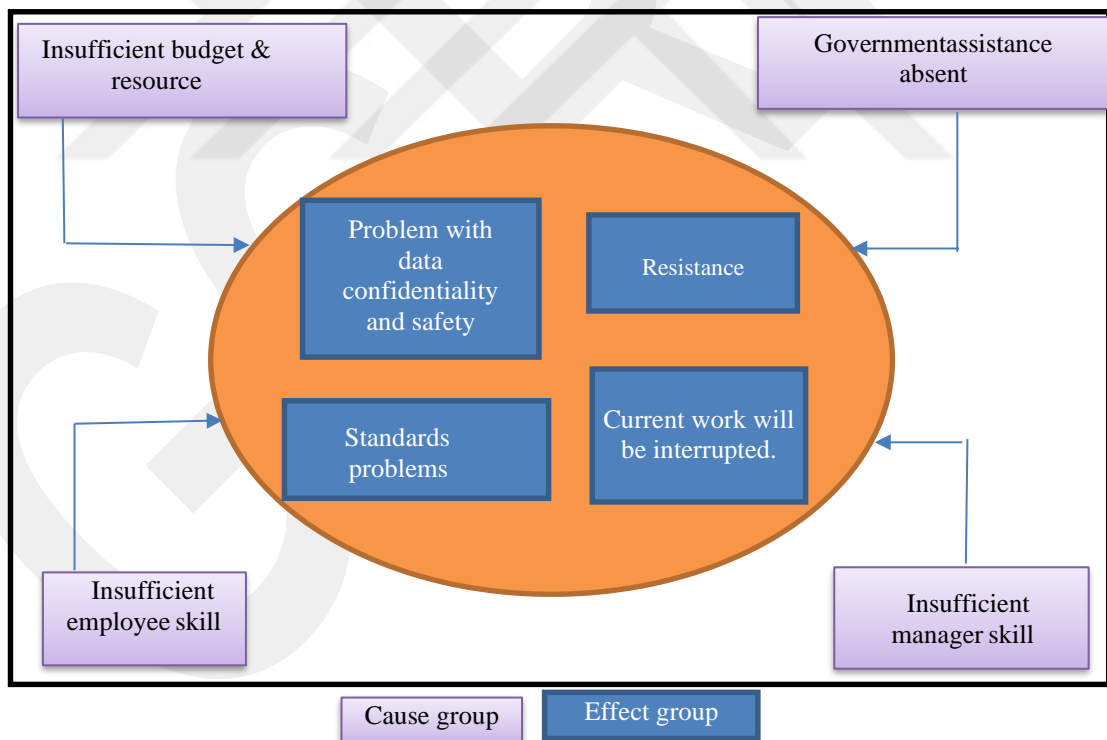


Figure 7 Cause-and-effect relationship diagram of barriers.

Regarding the finding drivers in this study, several studies have highlighted the importance of agility and flexibility in Industry 4.0 implementation. For instance, a study by Al- Turjman (2021) found that agility and flexibility are essential drivers of

Industry 4.0 in the context of supply chain management [46]. Similarly, a study by Khan et al. (2019) revealed that agility and flexibility positively influence the adoption of Industry 4.0 technologies in manufacturing firms. In addition, several studies have supported the role of government policies and legislation as a driver of Industry 4.0 [47]. For example, a study by Ahmad et al. (2020) found that favorable government policies can significantly influence the adoption of Industry 4.0 in small and medium-sized enterprises [48].

On the other hand, the barriers identified in this study also align with the findings of several previous studies. For example, the issue of data confidentiality and safety has been highlighted as a major barrier to Industry 4.0 adoption in various studies (e.g., Lacity et al., 2020; Nguyen et al., 2019) [49], [50]. Similarly, the issue of current work interruption has been identified as a significant barrier to Industry 4.0 adoption in several studies (e.g., Nofalet al., 2021; Susanty et al., 2021) [51], [52].

However, it is important to note that some studies have reported different drivers and barriers. For instance, according to Liao et al. (2019), availability of resources, including equipment, expertise, and finance, is a significant driver of Industry 4.0 adoption [53]. Similarly, Cai et al. (2018) found that having a strategic vision and goals can also drive the adoption of Industry 4.0 [54]. On the other hand, high initial investment costs have been identified as a significant barrier to Industry 4.0 adoption by Dwivedi et al. (2020) [55].

The contribution of this study is useful for academicians and practitioners that try to understand the implementation of Industry 4.0. The contributions of this study are:

- For academicians, this study covers that gap and develops a cause-and-effect relationship diagram of both drivers and barriers for the implementation of Industry 4.0.
- For practitioners, this study will increase their awareness of what they should pay attention to (barriers) and what they should focus on (drivers) when they are interested in the implementation of Industry 4.0.
- Revelation of the influence of Industry 4.0 on the business model.

CHAPTER 6

CONCLUSION

In conclusion, this study focused on investigating the drivers and barriers to implementing Industry 4.0 in small and medium-sized enterprises in Ankara, Turkey. The significance of Industry 4.0 in today's rapidly advancing technological landscape cannot be overstated, making it imperative to understand the factors that influence its successful implementation.

To achieve the study's objective, a survey method was employed, and the DEMATEL technique was utilized to analyze the collected data. The findings revealed five significant drivers and four significant barriers that play a crucial role in implementing Industry 4.0 within the selected context. These results contribute to the identification of key factors that need to be addressed for successful Industry 4.0 implementation, providing valuable insights for practitioners and decision-makers in the field.

The study's contributions extend beyond the identification of drivers and barriers. It includes the creation of a cause-and-effect relationship diagram, which visually represents the interconnections between the identified factors. This diagram enhances the understanding of the complex relationships and dependencies involved in implementing Industry 4.0.

However, it is important to acknowledge the limitations of this study, as it focused solely on small and medium-sized enterprises in Ankara, Turkey. Future research endeavors could expand the scope by incorporating large enterprises and participants from different countries. This would contribute to a more comprehensive understanding of Industry 4.0 implementation, considering a broader range of organizational contexts and cultural influences.

In summary, this study provides valuable insights into the drivers and barriers of Industry 4.0 implementation in small and medium-sized enterprises in Ankara, Turkey. The identified factors can serve as a foundation for organizations to strategically address challenges and capitalize on opportunities associated with Industry 4.0. Furthermore, future research efforts can build upon these findings to enhance our understanding of Industry 4.0 implementation across various contexts and scale. For

instance, examining its application in different cities, countries, or large-sized companies could provide valuable insight. Moreover, it is advisable to explore the interplay and impacts of factors within the same groups as a recommended avenue for future investigation.



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Appendix A : Questionnaire paper

Anket

Endüstri 4.0 olarak da bilinen dördüncü endüstri devrimi, organizasyon otomasyonunda ve verideğişiminde mevcut eğilimdir (Ahsan ve Ark., 2021). Bu mevcut eğilim hem KOBİ'ler hem debüyük işletmeler için sayısız engel ve etmen teşkil etmektedir. Sonuç olarak, bu çalışmanın bulguları, Endüstri 4.0 uygulamalarına etki eden en önemli engel ve etmenleri karakterize etmede endüstriye ve akademilere yardımcı olacaktır.

Tablo 2 ve 3 endüstri 4.0 uygulamasına yönelik etkenleri ve engelleri içermektedir. Sizden herfaktör için ikili Karşılaştırmanızı rica ediyoruz. Sıralama ölçeği aşağıdaki gibidir:

1=Etki Yok, 3=Az Etki,5=Orta Etki, 7=Güçlü Etki, 9=Çok Güçlü EtkiÖRNEK

Rahatlığınız için Tablo 1, 2 ve 3'ün nasıl doldurulacağınıza dair bir örnek göstermektedir. Örneğin B ile A' yi kıyasladığımız zaman, etki olarak 5 girilmiş (ilk sütun ve üçüncü satır) ve şu anlama gelir: B ile A karşılaştırıldığında Endüstri 4.0 uygulaması için B A' ya göre orta düzeyde motive

edici/engel edici etkiye sahiptir.[Sonuç olarak A ve B (birinci satır ve üçüncü sütun) 1/5 la etiketleniyor.]

Tablo 1: Karşılaştırma tablosu örneği

	Madde A	Madde B	Madde C	Madde D
Madde A	0	1/5	7	5
Madde B	5	0	9	7
Madde C	1/7	1/9	0	3
Madde D	1/5	1/5	1/3	0

Bu tablo gösteriyor ki; madde B, madde A üzerinde orta etkiye sahiptir. Madde B, madde C üzerinde çok güçlü etkiye sahiptir. Madde B, madde D üzerinde güçlü etkiye sahiptir. Madde A, madde C üzerinde güçlü etkiye sahiptir. Madde A, madde D üzerinde orta etkiye sahiptir. Madde C, madde D üzerinde az etkiye sahiptir. Böylece, madde B diğerleri içinde etki eden endominant maddedir.

Tablo 2: Endüstri 4.0 uygulamalarındaki etmenlerin ikili karşılaştırma tablosu

	Karlılık / artan verimlilik	Maliyetin düşürülmesi	Yenilikler	Endüstri 4.0 teknolojilerini uygulama Yenilik	Merkezi olmayan karar-alma	Çeviklik/ esneklik	Gerçek zamanda veri toplama	Verimlilik & kalite	Hükümet politikaları/ mevzuat	Çalışanların teknik becerilerini artırma
Karlılık / artan verimlilik	0									
Maliyetin düşürülmesi		0								
Yenilikler			0							
Endüstri 4.0 teknolojilerini uygulama Yenilik				0						
Merkezi olmayan karar-alma					0					
Çeviklik/ esneklik						0				
Gerçek zamanda veri toplama							0			
Verimlilik & kalite								0		
Hükümet politikaları/ mevzuat									0	
Çalışanların teknik becerilerini artırma										0

Buna ek olarak, lütfen yukarıdaki tabloda yer almayan üç veya daha fazla etmen belirtebilir misiniz?

Tablo 3: Endüstri 4.0 uygulamalarındaki engellerin ikili karşılaştırma tablosu

	Yetersiz bütçe ve kaynaklar	Yetersiz çalışan becerileri	Hükümet desteğinin yokluğu	Yetersiz yönetici becerileri	Direnç	Mevcut çalışmanın kesintiye uğraması	Veri gizliliği ve güvenliğine ilişkin problemler	Standart problemler
Yetersiz bütçe ve kaynaklar	0							
Yetersiz çalışan becerileri		0						
Hükümet desteğinin yokluğu			0					
Yetersiz yönetici becerileri				0				
Direnç					0			
Mevcut çalışmanın kesintiye uğraması						0		
Veri gizliliği ve güvenliğine ilişkin problemler							0	
Standart problemler								0

Buna ek olarak, lütfen yukarıdaki tabloda yer almayan üç veya daha fazla engel belirtebilir misiniz?

Bu tabloda, gizli kalmak ve paylaşılmamak üzere, kişisel bilgilerinizi

doldurmanızı rica ediyorum. [Tablo 4: Kişisel bilgi tablosu](#)

İsim	
Doktora/ Yüksek Lisans/ Lisans derecesi	
Meslek	
Pozisyon	
Deneyim süresi	