ANALYSIS OF INDUSTRY 4.0 TECHNOLOGIES' ADOPTION USING INTERPRETIVE STRUCTURAL MODELLING: EMPIRICAL FINDINGS FROM MANUFACTURING SECTOR IN TURKEY

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ABSTRACT

ANALYSIS OF INDUSTRY 4.0 TECHNOLOGIES' ADOPTION USING INTERPRETIVE STRUCTURAL MODELLING: EMPIRICAL FINDINGS FROM MANUFACTURING SECTOR IN TURKEY

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Emerging disruptive technologies, especially big data, the internet of things (IoT), cloud, cyber-physical systems, and 3D printing technologies, led to the emergence of a new industrial era called industry 4.0. The concept of industry 4.0, which emerged at the technology fair held in Germany in 2011, has established its foundations on increasing productivity in the industry and the digitalization of systems. Although industry 4.0 technologies have various benefits for the manufacturing sector, various difficulties may arise in the adaptation of these technologies. The aim of this thesis is to conduct a detailed study on the industry 4.0 revolution, to reveal the obstacles that may arise during the application of industry 4.0 technologies to the Turkish manufacturing sector, and to guide the managers who want to implement industry 4.0 applications in this direction, thanks to the roadmap obtained after the findings. Interpretive Structural Modeling (ISM) technique was used while establishing the relationship between the barriers in front of industry 4.0 adaptation. Thanks to ISM, the relationships between the barriers in front of industry 4.0 have been determined. This study will support managers in producing solutions that will reduce the impact of barriers to industry 4.0 adaptation.

Keywords: Industry 4.0, Interpretive Structural Modelling, Barrier, Adoption

ÖZ

ENDÜSTRİ 4.0 TEKNOLOJİLERİNİN ADAPTASYONUNUN YORUMLAYICI YAPISAL MODELLEME KULLANILARAK ANALİZİ: TÜRKİYE İMALAT SEKTÖRÜ ÜZERİNE AMPİRİK BULGULAR

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Büyük veri, nesnelerin interneti, bulut, siber fiziksel sistemler, 3D yazıcı teknolojileri başta olmak üzere ortaya çıkan yıkıcı teknolojiler endüstri 4.0 olarak adlandırılan yeni bir endüstri çağının ortaya çıkmasını sağladı. 2011 yılında Almanya'da düzenlenen teknoloji fuarında ortaya çıkan endüstri 4.0 kavramı endüstride üretkenliği artırma ve sistemlerin dijitalleşmesi üzerine temellerini kurmuştur. Endüstri 4.0 teknolojilerinin imalat sektörüne çeşitli yararları bulunmasına rağmen bu teknolojilerin adaptasyonu karşısında çeşitli zorluklar engeller oluşabilmektedir. Bu tez çalışmasının amacı endüstri 4.0 devrimi üzerine detaylı çalışma yapmak, endüstri 4.0 teknolojilerinin Türkiye imalat sektörüne uygulanması sırasında ortaya çıkabilecek engelleri gözler önüne sermek, bulgular sonrasında elde edilen yol haritası sayesinde endüstri 4.0 uygulamalarını hayata geçirmek isteyen yöneticilere bu yönde rehberlik etmektir. Endüstri 4.0 adaptasyonu önündeki bariyerler arasındaki ilişki kurulurken Yorumlayıcı Yapısal Modelleme tekniğinden faydalanılmıştır. Bu metod sayesinde endüstri 4.0 önündeki bariyerler arasındaki ilişkiler tespit edilmiştir. Bu çalışma yöneticilere endüstri 4.0 adaptasyonu önündeki engellerin etkisini azaltacak çözümler üretmeleri için destek olacaktır.

Anahtar Sözcükler: Endüstri 4.0, Yorumlayıcı Yapısal Modelleme, Bariyer, Adaptasyon

DEDICATION

To My Family

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LIST OF ABBREVIATIONS

3D	Three-dimensional
AI	Artificial intelligence
Digraph	Directed Graph
IoT	Internet of things
I4.0	Industry 4.0
R&D	Research and development
SSIM	Self-Structural Interaction Matrix
VR	Virtual reality

1. INTRODUCTION

Today, developments in technology support each other and when they are integrated for a common purpose, their positive returns are higher. With today's ever-increasing competition, companies have to renew their working methods with new technologies in order to maintain and improve their market shares in the sector (Birkie, 2015). When we look at the history of the industry, various methodologies have been used to improve the manufacturing process in the manufacturing sector. The main ones can be listed as follows: Frederick W. Taylor's scientific management method, lean production methodology, material requirements planning and enterprise resource planning. When the traditional production model is examined, it is seen that similar products are produced in high numbers in mass production. Although the need for volume in the market is met by the manufacturing of products in high quantities, with this production methodology, the products need to be more comprehensive in the face of the customized preferences of the users. At this point, there is a need for new production methods in which products can be produced specifically for individuals. The industry 4.0 revolution, which uses new production methodologies and aims to digitize every process of manufacturing as much as possible, first emerged in Germany for the development of the manufacturing process. It is expected that the user-specific manufacturing problem will be solved with the widespread use of industry 4.0 technologies, which have become increasingly widespread since 2010 (Yin et al., 2017a).

When the history of the industry process is examined, researchers agree that the industry went through three revolutions before industry 4.0. These revolutions are called industry 1.0, industry 2.0 and industry 3.0. Each industrial revolution started with its own unique technological developments and has different features in this context (Kohnová & Salajová, 2019). The mechanization of production was the first of the industrial revolution, with the emergence of the first machine using steam power in the middle of the 18th century. Industry 2.0, on the other hand, emerged with the use of assembly lines with machines working with electrical energy. The Scientific Management Principle published by Frederick Taylor is very critical for industry 2.0. In industry 2.0, there are two demands for products in society: volume and variety. Henry Ford, benefiting from Frederick Taylor's theory, developed mass production, and aimed to meet the volume dimension of demand (Yin et al., 2017b). The years between 1970 and 2010 in the industry can be called the third industrial revolution, in which the automation of production began. With industry 3.0, users' demand for products was not only limited to volume and variety but also added the dimension of delivery time.

With the developments in technology, it can be seen that the industry has stepped into a new era. In order to maintain their position in the manufacturing sector and to continue to compete in the international arena, especially industrialized countries have started new initiatives in order not to fall behind this new beginning. In 2012, the German Government adopted the action plan of the "High-Tech Strategy 2020" program. Although this program is a program that will cause very high costs to the government every year, the government has implemented the program because it believes that this plan will have high returns in the long run. One of the most striking projects among the projects in this program is industry 4.0, which reveals the goals and roadmap of Germany in the manufacturing sector (Kagermann H et al., 2013). The United States started to work in production with the "Smart Manufacturing Leadership Coalition 2011" plan in order to be at the forefront of the competition in production with new-generation technologies (Porter & Heppelmann, 2014). In 2015, the Government of Japan stated that it would follow the "Society 5.0" plan as a methodology in smart manufacturing. At the same time, the Japanese Government aims to create a new potential market that will make a great contribution to the state economy with the technological development it will achieve in production with the "Japan Rehabilitation Strategy" plan (*Report on The 5 Th Science and Technology Basic Plan*, 2015). The French government announced a strategic research plan called "La Nouvelle France Industrielle" during this period when destructive technologies started to come into play. The United Kingdom stated that it will activate the "Future of Manufacturing" plan for this new trend in industrialization and will follow the action steps in this plan (Kusiak, 2017). The Chinese Government announced that it will follow the "Made in China 2025" plan to increase the impact of information technologies in the manufacturing sector (Liao et al., 2017). In addition to this strategy, there is the "Internet Plus" policy, which plans to increase productivity in manufacturing by integrating traditional industry with the Internet and IT (Brown, 2016). The South Korean government launched the "Manufacturing Innovation 3.0" initiative in 2014 in order to be strong in the race for the technologization of manufacturing processes (MOON et al., 2018). In 2015, the Singapore government announced its own plan for the fourth industrial revolution as the "Infocomm Development Authority of Singapore (IDA)". In this plan, Singapore tries to achieve the goal of a "Smart Nation" by applying innovations not only in the manufacturing sector but also in the public dimension. In this way, it is believed that the new technologies applied will be permanent in the long term and their sustainability will be high. The list of major countries taking action in the digitalization revolution in the industry globally is shown together in Table 1.

Table 1: Major strategies of countries around the world for the industry 4.0 revolution

Date	**Country**	**Policy**
In 2011 In 2012	Germany	Platform Industry 4.0 High-Tech Strategy 2020
In 2011	United States (US)	Smart Manufacturing Leadership Coalition 2011 Advanced Manufacturing Partnership (AMP)
In 2013 In 2015	Japan	Japan Rehabilitation Strategy Society 5.0
In 2013	French	La Nouvelle France Industrielle
In 2013	United Kingdom (UK)	Future of Manufacturing
In 2014	South Korea	Innovation in Manufacturing 3.0
In 2015	China	Made in China 2025
In 2015 In 2016	Singapore	Smart Nation Master Platform Research, Innovation and Enterprise 2020 Plan

Source: Edited by the authors.

The scope of the concept of industry 4.0 may vary depending on the sector in which it is evaluated or the geography in which it is addressed. It can be broadly defined as: "integration of information technologies into the traditional industry; digitization and flexible structure of the process in the manufacturing system; digital tracking of manufactured products; active communication between sub-materials, products and machines where production takes place; ensuring optimization in production with high technology; Increasing productivity by obtaining a living smart production system, the continuation of processes with environmentally friendly methods" (Shafiq et al., 2016).

In the industry 4.0 revolution it is aimed to create a technology ecosystem by properly integrating cloud computing, autonomous robots, system integration, the internet of things, cyber security, additive manufacturing, big data, augmented reality, digital twins, virtual reality, 3d printing technologies.

In order for industry 4.0 to be implemented in organizations that continue traditional processes, traditional organizations need to be convinced of the value that digital transformation will bring here. In addition, while organizations understand industry 4.0, the challenges that will arise in the application should also be evaluated. Being aware of the barriers to industry 4.0 adaptation will be critical in producing solutions to these barriers or reducing the impact of barriers. Industry 4.0 is socio-technical systems. For this reason, it is necessary to be aware of the criticality of social factors during the industry 4.0 adaptation (Moghaddam et al., 2018). In addition to knowing the content of industry 4.0 during the implementation process, it is also critical to know the dynamics of the institution or factory where the application will take place. Depending on the size of the organization, manufacturing processes, and end-user criteria reached by the manufactured product, the application methods of technologies will be different. In the manufacturing sector, products are tangible; in the service sector, they are not. Different measurement methods should be used when examining the adaptation in these two sectors and the success of industry 4.0 (Bibby & Dehe, 2018). Considering the size of the organization, different studies have been carried out on small-medium enterprises. Considering that 90 percent of the companies in the European Union continue their processes as Small and Medium Enterprises, the work for these organizations is very valuable (Masood & Sonntag, 2020).

It is known that the implementation of these technologies in the IT sector is very fast. However, when the manufacturing sector is examined, it is seen that the implementation phase is slower and various difficulties are encountered. Adaptation to the new revolution in the manufacturing sector should be considered as a step-by-step process. Bosch, one of the leading companies in the adaptation of industry 4.0 technologies, states that the following factors are important in the adaptation process: First of all, it is a facilitated process as the effect of lean production; secondly, a factory with an information technology architecture and finally the integration of IoT, cloud and CPS systems is critical (Buer et al., 2020).

Thanks to the industry 4.0 application, it has been determined that services and products can be customized in line with user demands, supply times are shortened, product quality increases, long-term operating costs are reduced for the company, and production costs can be analyzed more comprehensively (Peukert et al., 2015).

The aim of this study is to examine the adaptation process of industry 4.0 technologies in the geography of Turkey, specific to the manufacturing sector. The criticality of the barriers to the adaptation process varies according to the geography and the sector studied. In the thesis, critical barriers will be identified and the relationship between them will be revealed. In the second part of the study, industry 4.0 technologies and the impact of these technologies on the manufacturing sector will be discussed. In addition, examples from the sectors and companies where industry 4.0 has been implemented will be given. At the end of the 2nd part, the driving power in the industry 4.0 adaptation obtained from the literature research and the barrier in front of the adaptation in other geographies and in other sectors will be presented with literature research. In the third part of the study, the opinions of the people working in the manufacturing sector were collected through a questionnaire. Based on the collected information, critical barriers to adaptation were identified. Thanks to the study using the Interpretive Structural Modeling (ISM) method, the relationship between the barriers will be placed in the ISM framework in a hierarchical structure. The aim of this study is to create a roadmap and guide the managers in the industry 4.0 adaptation process.

2. LITERATURE REVIEW

In this part of the study, the information obtained from the literature review is presented. In this direction, firstly, information about industry 4.0 technologies in the literature was given. The effects of the industry 4.0 revolution, in which the thesis work was privatized, in the manufacturing sector were stated. Examples of industries and companies that benefit from industry 4.0 technologies are given. Effective driving forces and emerging barriers during industry 4.0 implementations are listed. Finally, a SWOT analysis of industry 4.0 applications was carried out.

2.1. Industry Technologies

Industry 4.0, also known as the fourth industrial revolution, is characterized by the convergence of emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, augmented reality and cloud (Pereira & Romero, 2017a). These interconnected technologies are enabling businesses to collect and analyze massive amounts of data in real time, leading to significant improvements in efficiency, productivity, and decision-making.

Big Data and Analytics:

Big data refers to extremely large data sets that are too complex and large to be processed using traditional data processing tools. Analytics describes methods for analyzing, examining and extracting intelligence from big data. As a result, big data analytics can be seen as a part of the larger process of “extracting insights” from big data (Gandomi & Haider, 2015). This can involve using a range of techniques, such as machine learning algorithms, to process and analyze large amounts of data. Big data and analytics can be applied in a wide range of industries, including finance, healthcare, and genomics(George et al., 2014).

Common examples of big data analytics include analyzing texts from blogs, online forums, and to predict aircraft engine failure based on the data stream from thousands of sensors, analyzing sales data to identify trends and predict future demand, analyzing social media data to understand public sentiment and improve marketing campaigns(Gandomi & Haider, 2015).

Big data is playing a central role in industry 4.0. By leveraging advanced analytics and AI, companies can extract valuable insights from this data, allowing them to optimize their operations, improve customer experiences, and gain a competitive edge.

For example, DHL provides evidence that utilizing big data analytics improves operational effectiveness and opens up new business model exploration. Two components of the risk assessment analysis are included in "DHL Resilience360" along with tools that can practically real-time monitor the supply chain. Whether a production interruption happens determines the chain's strength and the resulting income losses; hence, this should be less likely to fail. The "The Forecast Number of Packages DHL" model, which has also been used in association with the study of Big Data, is currently in the experimental phase at DHL (Witkowski, 2017).

Additionally, big data can be used to improve customer relationships. By analyzing customer data, companies can gain a better understanding of their preferences, needs, and behaviors, allowing them to tailor their products and services to better meet their customers' expectations. This can lead to increased customer satisfaction and loyalty, ultimately driving revenue growth. For example, Retailers can fulfill the expectations of their consumers by foreseeing their behavior by using customer data to assess information from the delivery system (Witkowski, 2017).

Internet of Things (IoT):

IoT stands for the "Internet of Things". It refers to the growing network of physical objects that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices that connect users and systems over the internet. This allows these objects to "talk" to each other and to be controlled and monitored remotely. By allowing partners and systems to be accessed remotely in smart assembly, it decreases downtime and increases visibility into resource requirements, equipment performance, and security risks. It is an essential tool for enterprises with scattered production sites since it makes analysis easier and allows for better operational and quality decision-making (Ligneau, 2020).

IoT can help businesses to improve the efficiency and effectiveness of their operations by providing them with real-time information and insights that can be used to optimize performance. Overall, the use of IoT in industry 4.0 is helping to drive innovation and productivity in the manufacturing sector and beyond (Witkowski, 2017). The number of benefits from IoT technology around the world is developing very fast. The Number of IoT connections worldwide between 2016 and 2021 is featured in Figure 1.

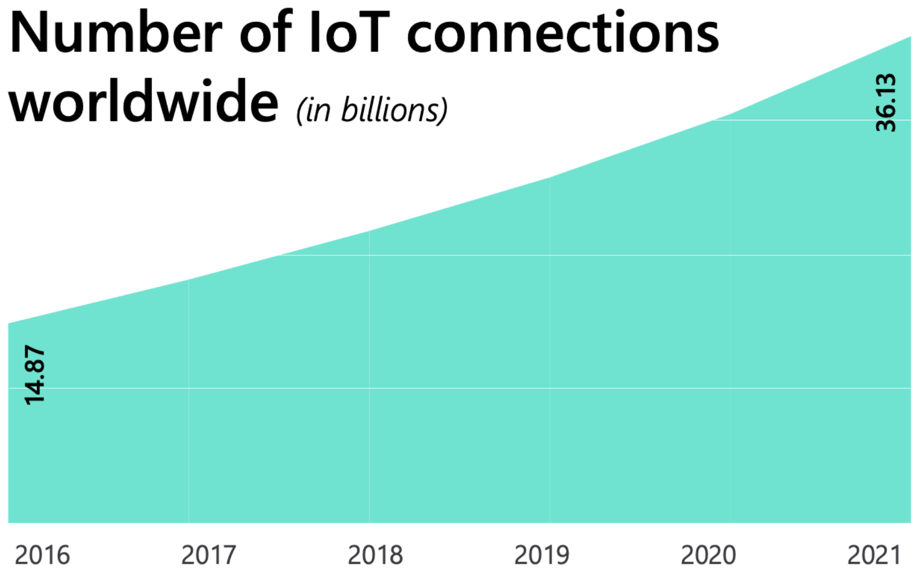

Figure 1: Number of IoT connections worldwide (“Manufacturing Trends Report Microsoft,” 2019)

Cloud:

Cloud computing is a model for delivering information technology services over the internet. It allows users to access and use the same types of computing resources (such as data storage, servers, and software applications) that are typically found in a data center but without having to manage the underlying infrastructure themselves. This means that users can access these resources on demand and only pay for what they use. The “cloud” in cloud computing refers to the internet, which is where all of these resources are delivered and accessed.

Cloud computing is the current trend of automation and data exchange in manufacturing and other industries. In this context, cloud computing is used to enable the efficient and effective operation of industrial processes and systems. With web-based apps, it offers convenience for operations. It is an effective way to manage Big Data. It simplifies infrastructure, enables instant access to information, transfers data across devices at high rates of speed and is usable by both small and large businesses (Ligneau, 2020). For example, cloud-based services can be used to store and manage large amounts of data generated by industrial processes, allowing businesses to analyze and make use of this data in real time. Salesforce.com, for instance, now provides a huge selection of cloud-based customer relationship management products. Users do not need to install and integrate the real software onto existing systems once a service contract is initiated; instead, their service is nearly immediately accessible to users. Users from throughout a company may access their data from any Web browser thanks to this, which may not only save a significant amount of time and resources. Cloud computing can also be used to host software applications and other tools that are used in industrial operations, such as product design, quality control, and supply chain management. Additionally, cloud computing can provide businesses with the flexibility and scalability they need to respond to changing market conditions and customer demands. For instance, well-known technology services providers like Amazon, Google, and IBM provide cloud products that let businesses rapidly grow systems to meet their capacity, collaboration, and coordination demands without compromising control or paying for extra, unnecessary capacity. Overall, the use of cloud computing in industry 4.0 is helping to drive innovation and competitiveness in the manufacturing sector and beyond (Wu et al., 2013).

Autonomous Robots:

Autonomous robots are robots that are capable of performing tasks without human intervention or control. The robots can be employed to carry out activities under predetermined conditions and concentrate on key elements, such as safety, versatility, adaptability, and cooperation with other robots and humans (Grufman & Lyons, 2020). Autonomous robots are used in a variety of applications, including manufacturing, agriculture, transportation, and search and rescue operations. They are often designed to operate in environments that are dangerous or inaccessible to humans(Bekey, 1998).

Robots are evolving in greater autonomy, adaptability, and cooperation. They will eventually communicate with one another, coexist safely alongside humans, and gain knowledge from them. Compared to the robots currently used in production, these ones will be less expensive and have a wider range of capabilities (Bahrin et al., 2016).

Cybersecurity:

Cybersecurity is the discipline of preventing attacks, damage, and unauthorized access on internet-connected systems, including hardware, software, and data. This is achieved by utilizing a range of tools, procedures, and techniques created to identify and stop cyber dangers like malware, ransomware, and phishing scams (Ligneau, 2020).

Cybersecurity is used to protect the systems, networks, and data that are essential to the operation of industrial processes and businesses. This can include measures such as encryption, authentication, and access controls to prevent unauthorized access to sensitive information. It can also include the use of firewalls, intrusion detection and prevention systems, and other technologies to detect and defend against cyber threats, such as malware, ransomware, and phishing attacks. For example, one of the brands that lack cybersecurity from online thieves is Yemek Sepeti. Hackers seized the usernames, last names, dates of birth, phone numbers, e-mail addresses, addresses, and passwords of 21 million YemekSepeti users. Following this, Yemeksepeti informed its users of the situation via e-mail. Yemek Sepeti received criticism for not managing the procedure well and for failing to protect personal information (Mavnacioğlu et al., 2022). The use of cybersecurity in industry 4.0 is essential for ensuring the integrity, reliability, and safety of industrial systems and data.

Additive Manufacturing:

Additive manufacturing, also known as 3D printing, is a type of manufacturing process in which a three-dimensional object is created by successively adding layers of material. This is in contrast to traditional manufacturing processes, such as machining or casting, which involve cutting away or pouring material to create a final product. Additive manufacturing allows for the creation of complex shapes and designs that would be difficult or impossible to produce using other methods.

Industry 4.0 involves the development of a digital world that incorporates aspects of the physical world and adds new levels of interaction. Everything is now digital, including business activities, working conditions, manufacturing processes, equipment, personnel, goods, and services. Within the digital environment, everything is connected. All of these technological developments, however, necessitate a sizable investment in R&D, and the "conventional" innovation process is highly drawn out. Engineers, therefore, discovered an answer: additive manufacturing. Rapid prototyping, layer manufacturing, and 3D printing are used to replace conventional production techniques. The latter is a method of building 3D objects on a computer using a layer-by-layer deposition of materials. It makes it possible to create intricate, unique goods with the most specific shapes (Ligneau, 2020).

Augmented and Virtual Reality:

Augmented reality (AR) and virtual reality (VR) are two related technologies that are used to create immersive, computer-generated environments. AR involves overlaying digital information and images in the real world, while VR involves creating a completely digital environment with that users can interact with. Both technologies are used in a variety of applications, including entertainment, education, and training (Ligneau, 2020).

AR and VR are used to improve the efficiency and effectiveness of industrial processes and systems. For example, AR is creating significant potential for service and maintenance by enabling on-the-spot repairs by regular staff. In the same way that industrial integration is a component of the fourth revolution process, this list can be expanded to incorporate blockchain and add industrial integration to the fourth pillar, which also covers enterprise architecture and application integration. VR, on the other hand, can be used for training and education, allowing workers to practice and learn new skills in a safe and immersive digital environment (Ligneau, 2020).

Simulation:

Simulation is a critical technique for creating planning and exploratory models to maximize decision-making, as well as the design and operation of complex and smart manufacturing systems. It might also help businesses assess the costs, risks, difficulties with adoption, effects on operational performance, and roadmap for industry 4.0 (de Paula Ferreira et al., 2020).

In order to obtain the best design, simulation is a crucial technique used to digitally shape products during the development phase. Without needing to actually build a prototype, it enables process, system, and configuration testing, which has several benefits, particularly when developing a complicated product or system. By modifying operation features, such as size, colors, materials and coding sequences, engineers can visualize and evaluate numerous configurations and scenarios before they are really implemented (Ligneau, 2020).

Industry 4.0 Technologies are visualized together in Figure 2.

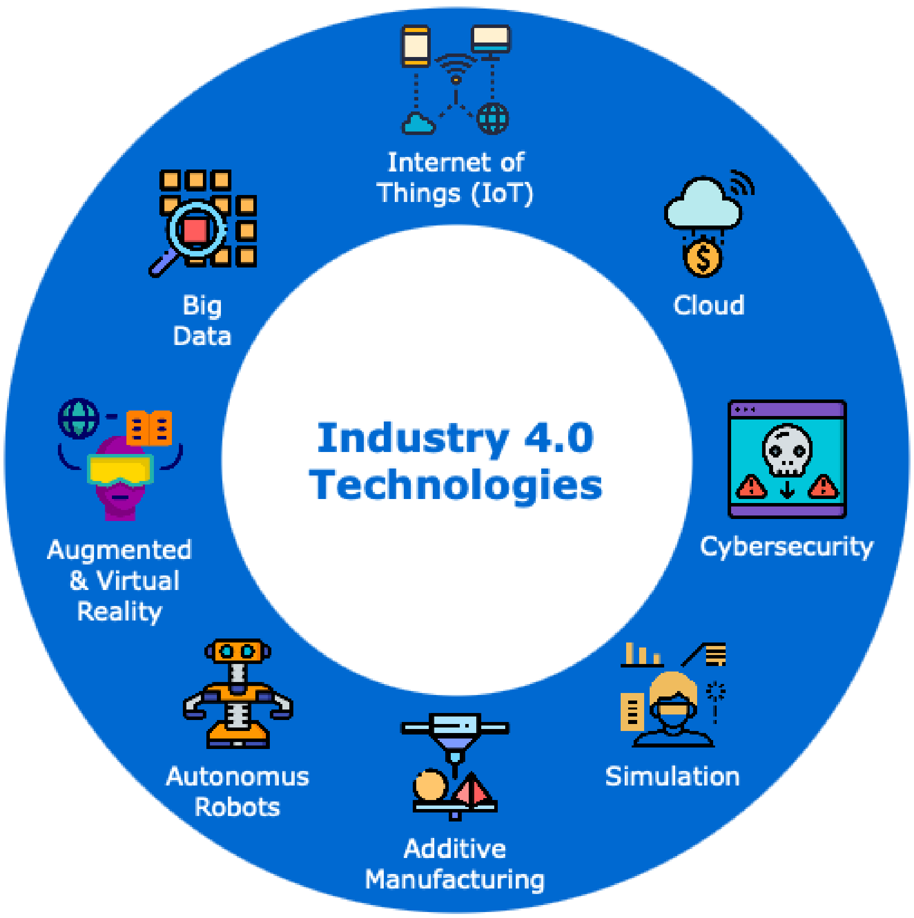

Figure 2: Industry 4.0 Technologies

2.2. Industry 4.0 Impacts on Manufacturing

Each industrial revolution has had critical effects on manufacturing. When the literature is examined, the cornerstones, technological developments and critical features of each revolution can be seen. With the use of steam engines in the manufacturing sector, some of the manual labor was replaced by the manufacture of machines. At the same time, the power of the steam engine revealed new production methods. Especially the cotton weaving sector and the iron and steel sector are the leading sectors in this revolution (Başer, 2011). With mechanization, an increase in productivity and volume of production has been observed. The critical development in the second industrial revolution is the use of electrical energy in production and the transition to mass production. The development of railways and other transportation facilities created a suitable environment for the 2nd Industrial Revolution. With the second industrial revolution, both the variety of products in production increased and the volume dimension increased. Digitization in the industry 3.0 revolution has shortened production times in the manufacturing sector. Automation systems brought about by digitalization have begun to replace the human workforce in certain sectors. The industry 4.0 revolution began in the 21st century with new disruptive technologies such as IoT, cloud systems, 3d printer and big data added to the production sector. The critical characteristics of industrial revolutions are shown in Figure 3 in chronological order.

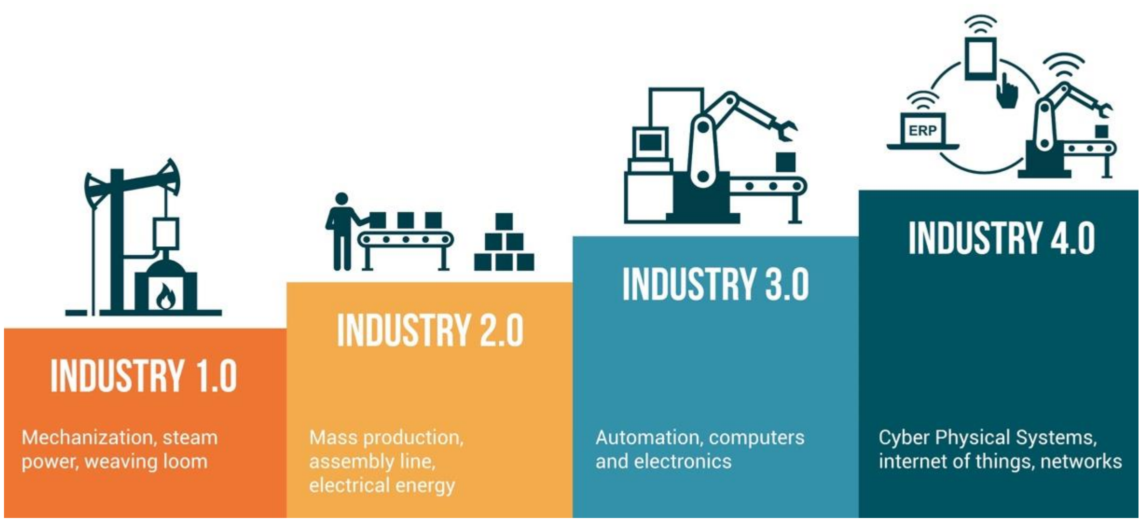

Figure 3: Industry revolutions (Elenabsl, 2017)

With the industry 4.0 revolution, unlike the previous revolutions, the product produced in high volumes with mass production in society today has begun to be replaced by personalized products (Pereira & Romero, 2017b). In today's consumption world, users prefer to use products that are rare and have special touches on them. Customizing the products produced according to customer needs is critical for companies to maintain their position in the market. For this reason, changes have begun to occur in the production methods that can provide this privatization.

Managers in a manufacturing company with successful connectivity can instantly analyze data from the system. It is possible to anticipate customer demand and manufacture accordingly, with instant information coming from stores where they can see customer requests, warehouses where they can see the number of products in stock, and production lines. As the manufacturing factory becomes digital, data will be collected from every process, from the product received as raw material to the factory, its production at the factory, its distribution to the distributors and then its delivery to the end user, and the size of the data obtained will increase as the integration of technologies increases. All these data collected thanks to the internet of things are stored in cloud systems and the transformation of this data into valuable information is provided by big data.

With industry 4.0 technologies, the dominance of autonomous robots in production and assembly lines has increased. Autonomous robots that repeat similar functions, as well as robots that improve themselves with machine learning technology and can perform more complicated tasks, have started to be used in the manufacturing sector. As these robots gain experience, the success rate of these robots in their tasks increases thanks to machine learning. Autonomous robots can optimize their action speed by following the production line with smart algorithms. By working according to the manufacturing need without the need for human intervention, they save up to 30 percent in energy compared to the robots in the industry 3.0 revolution (Beier et al., 2018).

With the developments in technology, the costs of robot technologies are decreasing. The cost of integrating a single industrial robot into the factory was approximately $150,000 in 2010. By 2015, the cost of integrating an industrial robot into a manufacturing plant had dropped to about $25,000. The change in the cost of industrial robots from 2010 to 2015 is visualized in Figure 4 (“Manufacturing Trends Report Microsoft,” 2019). This reduction in cost is expected to continue with advances in technology. The cost of sensors, which is very critical for smart manufacturing in factories, decreased by approximately 200 percent from 2004 to 2018 (“Manufacturing Trends Report Microsoft,” 2019). The time to integrate robot technologies into production lines is shortened. This has increased the supply of robots worldwide over the years.

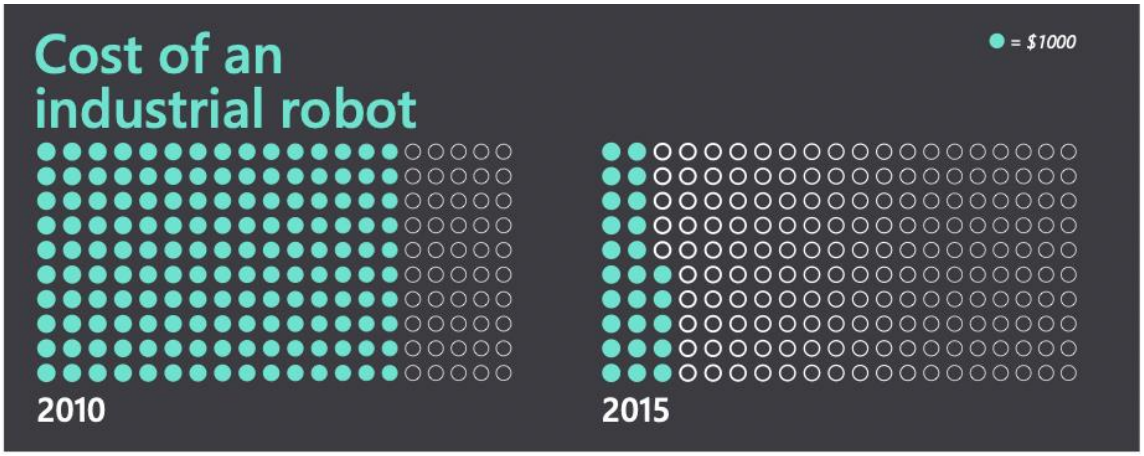

Figure 4: Cost of an industrial robots in 2010 and 2015. (“Manufacturing Trends Report Microsoft,” 2019)

The annual supply of robots according to the robot supply between 2009 – 2020 and the estimation of the robot supply between 2021-2024 are shown in Figure 5. Although the Covid-19 epidemic, which has a global impact, has reduced the amount of annual installation of industrial robots compared to previous years, it is expected to reach record levels in the coming years. In the other Figure 6, the annual installation of industrial robots 15 largest market information in 2020 is given. The largest market for industrial robots was China, with around 168400-unit robot installations. China was followed by Japan and the United States, respectively. The sector information in which industrial robots are used is shown in Figure 6, according to the information for 2018, 2019 and 2020. While the automotive sector was the sector with the most industrial robot installations in 2018 and 2019, the electrical/electronics sector was the sector with the most installations in 2020. Robots are preferred in dangerous or health-threatening parts of manufacturing factories. Robots provide uninterrupted service if they are powered uninterruptedly and maintained regularly. They perform their tasks more consistently and with less error than humans. Although robots have advantages compared to humans, the study carried out by Klump et al. in 2018 showed that the most optimized solution in the manufacturing sector is the integrated operation of human-robot mixed systems (Klumpp et al., 2019). In the studies, it is recommended that robots work together, not replace humans, in smart manufacturing production lines carried out in smart factories (Gradim & Teixeira, 2022). Employees in human-robot collaboration will need training. Robots give advance notice of their maintenance times. This reduces unexpected stoppages in production. It is predicted that the approach of predicting the failure situation determined from the data transmitted by the robots will reduce the cost by close to 600 billion dollars per year (Nicolaus Henke et al., 2016). Today, 9% of factories in the manufacturing sector benefit from autonomous devices (“Manufacturing Trends Report Microsoft,” 2019). Industry 4.0 has had an impact on the manufacturing sector in terms of changing the employee profile, changing the production method, increasing the number of products and increasing the product variety.

Figure 5:Annual installations of industrial robots 2015-2020 and 2021*-2024* (World Robotics 2021)

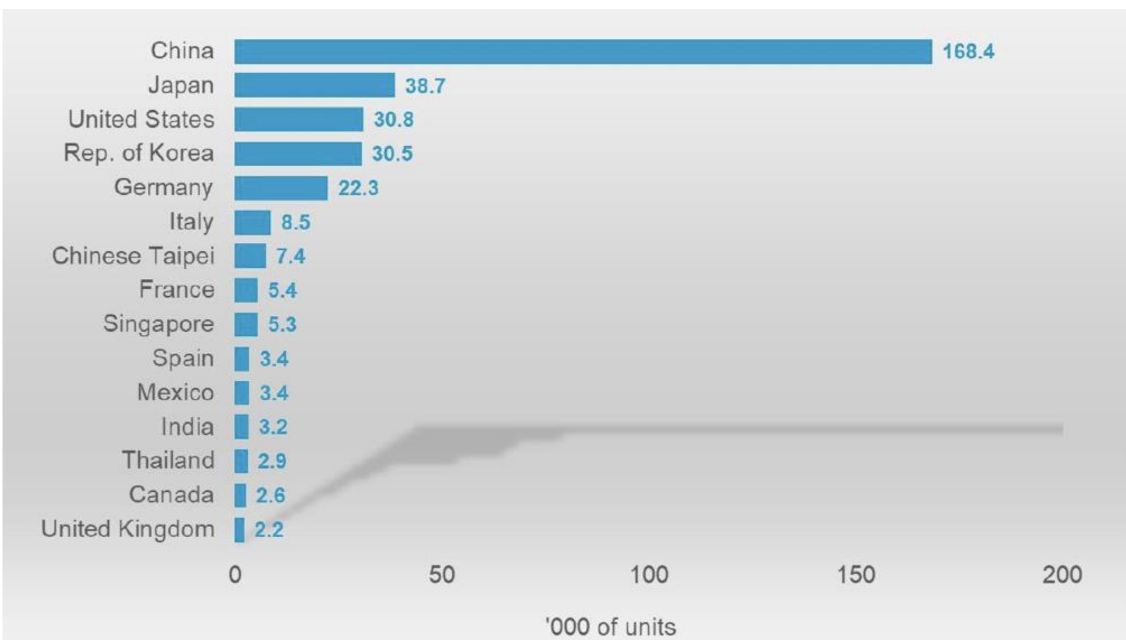

Figure 6: Annual installations of industrial robots in 15 largest markets in 2020 (World Robotics 2021)

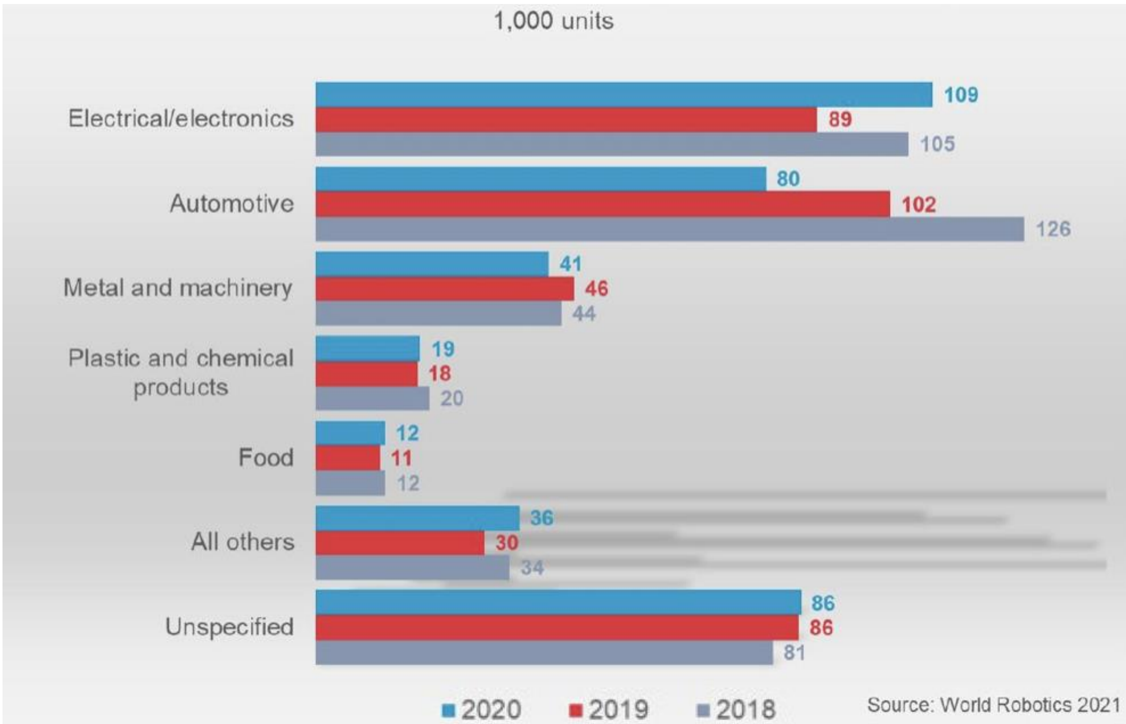

Figure 7: Annual installations of industrial robots by customer industry (World Robotics 2021)

With industry 4.0 technologies, the manufacturing sector today has instant information about the products they produce. They make their production plans according to the feedback they receive from the end users in the field. In fact, thanks to the trend information they can reach, companies can launch new products by making new designs in line with this trend. In this way, the manufacturing sector can more closely follow the preferences of the customer.

Cyber systems enabled by industry 4.0 are systems that can make their own decisions according to the needs of the manufacturing. In this way, decentralized decisions can be made in manufacturing plants (Chen et al., 2017). In the factories where industry 4.0 is successfully applied, there is no need to have an employee physically to start the production or stop the production line. This reduces the labor cost in manufacturing.

Industry 4.0 has also affected the manufacturing sector with the concept of Quality 4.0. Quality 4.0 guides the quality standards in the manufacturing process of manufacturers using industry 4.0 technologies and improves quality standards by using new technologies. For Quality 4.0, systematic inspection of equipment is very critical. With systematic inspections, precautions are taken before a malfunction occurs in the equipment. With this method, more than 10% gain from maintenance costs can be achieved, while production losses can be reduced by 20% (Close, 2017). Visualizing the process from the raw material to the end user facilitates bottleneck detection. Organizing the resource allocation according to bottleneck detection ensures the optimization of the resources. The use of the cloud, one of the industry 4.0 technologies, reduces information technology hardware costs (Alcácer & Cruz-Machado, 2019).

Products designed in the manufacturing sector can be tested in detail at the design stage with design programs. Thanks to industry 4.0 Simulation, the behavior and output of the system can be analyzed according to the inputs in a very short time. In this way, industry 4.0 makes a great contribution to the design phase of the manufacturing sector. Every stakeholder in the manufacturing process can easily access the results of the tests performed in the digital environment. The use of 3D printing in the manufacturing process positively affects the prototype production process. Instead of being produced and assembled as separate parts, the products can be printed in one piece thanks to 3D printing. The production line is optimized by testing the structure of the production lines in simulation.

Industry 4.0 has an impact on the supply chain, which means that the raw materials of the products become products from the suppliers and then reach the user. Thanks to the digital media used, information exchange between suppliers, manufacturers, retailers and users has increased. In the digitalized environment, information exchange between stakeholders is more open and this shortens the life cycle of the product. Thanks to industry 4.0, it has been possible for the manufacturing factory to react quickly to orders from customers and to deliver them to the customers with successful logistics (Tjahjono et al., 2017).

2.3. Sectors where Industry 4.0 is applied and its effects

With the benefits of industry 4.0 technologies being seen, industry 4.0 has become widespread in many sectors. It can be said that the manufacturing, health, agriculture, energy and transportation sectors are the main sectors where industry 4.0 has started to become widespread. In the manufacturing sector, industry 4.0 takes place at every stage, from the production of the raw material to the delivery of the final product to the user. Remodeling the supply chain structure. It reduces waste by optimizing production lines. It ensures the production of quality products by reducing the error rate. White goods manufacturing and automotive manufacturing are the business areas that benefit most from industry 4.0 technologies in this manufacturing sector.

Industry 4.0 technologies enable the production of patient-specific devices in the health sector and facilitate patient care. At the same time, it is effective in regulating hospital management and density. Remote monitoring of people with amnesia can be done with IoT devices, and the patient’s disease history can be analyzed to reveal their tendencies to future diseases.

In the construction sector, industry 4.0 technologies are used in the realization of architectural designs, simulating various external factors and optimizing the durability of the structures to be constructed. Industry 4.0 technologies have also been beneficial in the establishment of online markets in the retail sector, improving inventory management and optimizing the supply chain. The data obtained in the energy sector can be stored thanks to the cloud and meaningful information can be obtained from these data thanks to big data. Thanks to the industry 4.0 technologies used in the mining industry, the risk of a dangerous work environment is minimized. In addition, geological modeling in the mining sector has also become possible. It was reported in the World Economic Forum that 610 million tons of CO_2 footprint could be reduced through digitalization in the mining sector during the years 2016-2025 (Sishi & Telukdarie, 2017).

Industry 4.0 is used in the transportation sector by working on the smartening of traffic lights and the analysis of instant data from the traffic. Resource optimization is achieved by taking into account the density of public transportation vehicles. In addition, in terms of vehicle maintenance, smart vehicles inform their owners of breakdowns much earlier.

Industry 4.0 technologies are used in the agriculture and livestock sectors. With sensors and cameras, barns and pastures can be monitored instantly and information can be collected. The collected data can be transferred to interfaces such as Resberrypi or Arduino (A. Sharma, 2020). Thanks to the platforms where instant information about animals can be stored, information about their past is kept ready, this information can be analyzed and predictions can be made for the future. Thanks to big data technology, livestock and crop data are analyzed. Thanks to various applications developed, farmers can produce by taking into account the market demand and thus increasing their earnings. Thanks to simulation programs, farmers can predict what their output will be in different scenario planting or animal breeding inputs in different scenarios on their lands. With the development of algorithms in data analytics, more accurate assumptions about harvest quantity and variety are obtained (N. Sharma, 2020).

2.4. Companies That Used Industry 4.0

Companies that have successfully implemented industry 4.0 adaptation and increased their productivity are ahead of their competitors in the competitive race. As the benefits of industry 4.0 are seen, these successful companies set an example for other companies. In this section, companies that have successfully applied industry 4.0 technologies, pioneered the fourth industrial revolution and demonstrated the benefits of industry 4.0 are mentioned.

Established in 1886 in Stuttgart, Germany, Bosch is one of the most established companies in the world. It is a company that has played a role in the emergence of industry 4.0 methodologies, pioneered its implementation, and even is one of the ideas of the industry 4.0 revolution. Production with networked machines and production lines is planned to self-optimize according to the effect of various variables.

Volkmar Denner, one of the senior managers at Bosch, argued in 2017 that thanks to his achievements in industry 4.0, there will be a financial return of more than one hundred million euros every year after 2020 (Salomé, 2020a). The company achieved sales of over 700 million Euros in 2020 thanks to its industry 4.0 production solutions (Bosch Türkiye, 2021).

Defending the necessity of common standards for industry 4.0 technologies to work in an optimized way, Bosch played a role in the development of the OPC UA machine language. It is argued that industry 4.0 should not be seen as a risky approach, and it is the normal approach that should be for companies that want to be successful in the future.

Since 2011, the company has saved 25 percent in maintenance costs, 15 percent in idle use of machines, and 25 percent in production thanks to industry 4.0 applications (Bosch Türkiye, 2021). It benefits from the IoT and Big Data while monitoring the process in Bosch factories in real-time. In addition, the device that controls nearly 22000 machines is in communication with each other. Bosch uses the "Balancing Energy Network" system to optimize energy consumption in its factories. Although it is currently only used in its own factories, this system, which reduces energy consumption, has the potential to be used in centers such as shopping centers and hospitals. While this system provides companies with financial gain by reducing energy consumption, it also allows green production that protects nature.

Bosch continues the tests of 5G Technology, which provides about ten times the data transmission speed compared to the previous generation mobile telecommunications service and has also started the production of 5G-enabled products. In this regard, Bosch includes three principles in its vision: firstly, to treat industry 4.0 as inclusive; secondly, open architecture for user-friendliness, and finally, flexible production for more customization of products.

With its experience in Bosch industry 4.0, it also provides consultancy services to other production facilities that want to make progress in this regard. White goods production, automotive production, textile and steel industry sectors are some of the sectors it provides this service. It uses Bosch IoT Cloud, which it developed itself in cloud technology.

Volkswagen, an automotive manufacturing company established in Berlin, Germany, has 122 production plants. The company, which makes high investments in R&D studies by following technological developments very closely, also uses industry 4.0 technologies in its production lines. Digitizing the production process, the company aims to establish an industry-specific cloud system by utilizing Amazon web services. Thanks to this industry-specific cloud, it is aimed to increase production capacity by 30% (Salomé, 2020a). It is aimed to increase technological developments by making this platform accessible and developable for other companies in the automotive sector in the future.

Siemens is another company that digitizes its production and uses the latest technologies on its production lines. Benefiting from the technology of the internet of things, it also values cyber security studies (Santos et al., 2017). It uses the data it receives from the production lines in its simulations. The system, which simulates different scenarios on critical issues that managers need to take, supports the decision mechanism. He created the IoT operating system that uses the Cloud technology base he named “Mindsphere”. Actively uses this system in 20 centers (Kesayak, 2022).

General Electric company manufactures its devices, parts and products with a digitalized manufacturing system. The company, which continues its production in 175 countries, provides a connection by making smart machines communicate with each other. GE Digital and Türk Telekom companies work together to advise industrial companies in Turkey on digitizing their factories. GE Turkey has started to transform its factory in Gebze, where it produces power transformers, into a smart factory with the industry 4.0 approach. The company, which has more than 330 thousand employees worldwide, is very effective in the digitalization of the industry.

3d printer technology, one of the industry 4.0 technologies, has been very effective in shoe manufacturing. In 2012, Nike, one of the successful companies in the shoe manufacturing industry, started this business by patenting the method of producing shoes using a 3d printer. Another giant company in the shoe manufacturing industry collaborated with the company Carbon, which is very successful in 3d printing with Adidas 3d printer (Sart, 2020). Thanks to this study, Adidas shortened the time from the design of the shoes to the delivery to the end user by about six months (Cheng, 2018). Adidas believes it will increase the customizability of products as it equips its manufacturing plants with new technologies. It develops its working methods in this direction. Continuing its shoe manufacturing in regions where the workforce has been cheaper for many years, Adidas aims to manufacture shoes in the Speed Factory factory without the need for any human intervention. It introduced the Speed Factory facility with the slogan “The future of how we create”. In this respect, the fact that the manufacturing factories will not need cheap manpower may cause the production to shift from the Far East to America and Europe (Pamuk & Soysal, 2018).

Airbus company, which follows highly technological approaches in aircraft manufacturing, benefits from the advantages brought by the industry 4.0 revolution. When parts are produced using 3D technology, the weight is reduced by 55 percent per part. Each kilogram of reduction in the total weight of the aircraft produced as a result of production using less raw materials prevents a 25-tonne CO_2 footprint when considering the average time the aircraft has been used (Salomé, 2020b). Thanks to the advantages of additive manufacturing, Airbus has reduced the cost of manufacturing. The company, which makes use of IoT technology in its manufacturing factories, aims to use this technology to increase customer satisfaction during flights and to provide convenience to cabin crew. For example, thanks to the sensors placed on the seats, it is checked that the passengers are in the fastened position of the belts.

The IBM company, which is active worldwide, has taken very effective steps in digitization technology. The company provides consultancy on the way to digitalization with IBM Cloud Pak, IBM DB2 and IBM Watson IoT Platform systems, an artificial intelligence application. It provides support in a wide variety of areas ,such as cybercrime detection, the health sector, personalized shopping, and the autonomous vehicle sector.

2.5. Driving forces to implement Industry 4.0

While evaluating industry 4.0, it will be useful to examine the factors that will lead manufacturing factories to implement industry 4.0 revolutions. With the developments in technology, new production methods, and the shortening of product life cycles, competition in every sector has increased. Companies have increased their production capacity and increased their production speed in order to be on the winning side in this race. (Bauer et al., 2015a). Companies that digitized their production continued their continuity, and those who could not keep up with this technology were eliminated from the market. Trying to apply traditional production systems is a waste of effort in the current manufacturing sector.

The wastes generated by outdated traditional production systems harm nature due to high energy expenditures. The increase in the use of industry 4.0 technologies is an important step toward a more livable and sustainable World in this respect. Manufacturing factories integrating industry 4.0 technologies should take environmentally friendly actions (Koenig et al., 2019). Environmentally friendly production of industry 4.0 is one of the driving forces.

Thanks to new production models and technologies, it has become possible to manufacture customized products according to user demands. It is one of the forces that make industry 4.0 attractive to manufacturing companies who see this opportunity. If the company's R&D power and perspective on innovation are high, the successful implementation of industry 4.0 will be possible.

New business models are expected to emerge thanks to industry 4.0 technologies. While increasing the value of the resulting product, it will also enable new methods to be found to create value. With the emerging new business models, traditional manufacturing processes will turn into new ones (Ustundag & Cevikcan, 2018).

The success of industry 4.0 requires a strong network infrastructure. In this regard, the government's provision of this infrastructure will be one of the driving forces. In addition, the government's giving various incentives, such as financial support to manufacturing factories that implement new technologies, will speed up the process. In this process, where all information is digitized, it is critical that the government develops laws on data protection and that penalties are deterrents for malicious use of data.

Rolf Najork, one of the Bosch senior executives, advocated that a collective and global approach is needed for the industry 4.0 revolution to be used to its fullest extent. He stated that it is critical that the same language should be spoken in the globally determined standards during the human-machine cooperation study (Bosch Turkiye, 2021). Ensuring these standards will be one of the driving forces. Organizations such as Platform Industry 4.0 and the Industrial Internet Consortium are working to decide on these standards.

One of the driving forces for the successful implementation of industry 4.0 is the belief and leadership of the top management in this change. Managers who realize the potential of industry 4.0 should both increase the motivation of their employees and allocate resources for industry 4.0. Financial investment support that the company will devote to innovations is a critical factor. Success will come when high investment is used in the right places.

The driving forces obtained as a result of the literature review are shown together in Table 2.

Table 2: Driving forces for industry 4.0

Driving Force	**Source**
The power of research and development (R&D)	Eltayeb et al., 2021
Government policies	Krishnan et al., 2021, Eltayeb et al., 2021
Eco-friendly manufacturing	Lins & Oliveira, 2017
Top management’s interest	Kumar et al., 2020
Customization according to user demands	Adolph et al., n.d.
Competitive advantage	Bauer et al., 2015b
Financial support	Kagermann et al., 2013
Reduction of costs	Eltayeb et al., 2021
Facilitating the flow of information	Eltayeb et al., 2021
Increased productivity	Paritala et al., 2017
International standards	Bosch Turkiye, 2021

2.6. Barriers to Industry 4.0 implementation

The benefits and potential power of the industry 4.0 revolution are very high. It is very valuable that this revolution is embraced by society and spread in every sector. Managers in the industry need to use the most up-to-date technologies to increase productivity and advance their position in the market. At this point, there are various obstacles that slow down the industry 4.0 adaptation and apply resistance to the adaptation. In order for managers to successfully implement the industry 4.0 revolution, they need to be aware of these barriers and make preliminary work on the solutions to these barriers. When a literature review is conducted on this subject, it can be seen that various studies have been carried out.

Prasanth Senth Paduval listed the barriers obtained from the literature under five different headings: Management, Maintenance and Modifications, Costs, and Culture (Poduval et al., 2015). Top management’s disbelief in adaptation, the desire to allocate fewer resources, trying to adapt to the system without piloting, the resistance applied by the organization, wrong team distribution, and the need for training are some of the barriers mentioned in the research.

One of the biggest barriers to industry 4.0 implementation is the need for high costs. In the first phase of the implementation of disruptive technologies, high fixed costs emerge. Companies in the industry may not have the financial power to invest in expensive equipment and software for the implementation of industry 4.0 technologies. This high-cost feature can be a deterrent for small and medium-sized enterprises.

Skilled workers are needed to ensure sustainability in the application of advanced technologies. However, the personnel working in the majority of the factories that continue traditional production do not have information about new technologies. Specialized knowledge and skills are needed for the adoption of industry 4.0 technologies. One of the barriers is that the personnel profile is not compatible.

The digitalization of company data with the application of new technologies can raise concerns about data security issues. Protecting this data is as critical as collecting and analyzing data. Protection of this information may be even more critical for R&D companies and companies in the defense industry sector. The risk of information being stolen by malicious people is one of the barriers.

Finally, cultural or organizational resistance to the change that industry 4.0 will bring may also be a barrier to industry 4.0 adaptation. Company executives and company personnel may be hesitant to adapt to new processes and technologies, as critical changes in the way they do business and the way they operate may be necessary. Overcoming this barrier to change will be very valuable for the success of industry 4.0.

The critical barriers determined as a result of the literature study are shown together in Table 4 by specifying their sources in part 3.1.

2.7. SWOT Analysis of Industry 4.0

Making a SWOT analysis of the industry 4.0 revolution will be useful for evaluating the returns of these disruptive technologies from different perspectives. SWOT analysis is a type of analysis used to reveal the strengths, weaknesses, opportunities and threats of the subject studied. This thesis study deals with the barriers to the adaptation of industry 4.0; the purpose of this study is to deal with industry 4.0 in these four aspects. This study will also contribute to creating a roadmap for managers during the industry 4.0 adaptation, which is one of the aims of the thesis.

Automated processes with the use of industry 4.0 technologies in manufacturing ensure that production is optimized. In this way, the productivity of the manufactured products increases. With digitalized systems, they can directly see the customer's demand and can manufacture by taking this demand into account. Thanks to this advantage, it has superior competitive power. With the use of disruptive technologies in processes, new value-added business areas are emerging. In addition, while technologies were integrated, new manufacturing methods were gained. Instant monitoring of every stage of the manufacturing process enables fast action against external factors. Mentioned here are some of the strengths of industry 4.0.

Industry 4.0 has both strengths and weaknesses. High-cost investment is required for the implementation of industry 4.0 technologies. This cost is the weakest aspect of industry 4.0, especially for small and medium business firms. Successful implementation of these technologies requires trained personnel. However, the number of trained personnel is very limited in the factories that continue their production with traditional methods. Ensuring the reliability of the information in the factory with the digitization of the whole process is another weakness of industry 4.0. Factories that do not have successful digital protection are concerned about this. The innovations brought by industry 4.0 may cause resistance by the personnel who do not want to give up their habits.

The advantages brought by industry 4.0 technologies include forward-looking opportunities. The most important of these is the provision of environmentally friendly production on a global scale, thanks to ecological production. Technologies that optimize energy consumption include environmentally friendly methods with the philosophy of manufacturing with minimum waste. It is expected that new technologies used in the manufacturing process will reveal new markets. This is a critical economic opportunity for the future. Since industry 4.0 is a global movement, it is expected to increase global cooperation and coordination. Reducing costs with increasing integration of industry 4.0 technologies is another economic opportunity.

The industry 4.0 revolution will change the way industries operate. This change involves several risks. Untrained personnel may experience job loss due to their low contribution to the functioning of new technologies. Since the industry 4.0 adaptation is a new process, it is difficult to predict the long-term returns of the roadmaps in the literature. Roadmap additional status is a risk for factories with long-term investments. The fact that the data is in the digital environment poses a threat to malicious people to steal the information. Since the platforms are not mature enough yet, common languages that need to be established in the digital environment have not been formed. This is a threat that may require companies to take steps for industry 4.0 to make changes in the future. The data obtained from every stage of the manufacturing process reveals very high data. Although the processing of this data is possible thanks to Big Data, the algorithms have not yet developed very comprehensively. The policies of the states regarding industry 4.0 are still unclear. The possibility that government policies in the future will limit industry 4.0 yields is a threat.

The SWOT analysis of the industry 4.0 revolution is shown in Table 3.

Table 3: SWOT analysis of industry 4.0

Strengths	**Weaknesses**
• Increasing productivity • Competitive advantage • New business areas and manufacturing methods • Live to monitor of the manufacturing process	• Need for high-cost investment • Lack of trained personnel • Security issues • Personel resistance
Opportunities	**Threats**
• Ecological, environmentally friendly manufacturing process • New market opportunities • Global collaboration and coordinated work • Reduction of costs	• Job loss • Lack of roadmap and implementation method • Data theft • Lack of platforms • Inadequacy of data analysis algorithms • Goverment policy • Economic constraints

3. METHODOLOGY

In this section, the methodology to be used during the research will be presented. The quantitative experimental research methodology was used during this study. Interpretive Structural Modeling (ISM) method was used during the study. Using this method is aimed to model the relationship between the barriers in the adaptation process to industry 4.0 technologies. The ISM methodology helps to simplify the relationships between parts of the system being studied from a complex situation. The reason for using the ISM methodology during this study is that there is more than one variable in front of the adaptation of industry 4.0 technologies to the production sector and the aim of the study is to determine the relationship between these variables. Singh and Deshmukh (2007) define the ISM methodology as an interactive learning process (Singh et al., 2007a). The ISM methodology applied in the study will be a resource for managers to re-evaluate the priorities of the barriers identified in the study.

Thanks to the ISM methodology, the interconnections and mutual influences between the barriers to industry 4.0 adaptation will be examined. These barriers will be systematically analyzed using the ISM methodology and presented in a more understandable format. The framework to be obtained as a result of the study will reveal the hierarchical structure between the barriers. In addition, the ISM methodology reveals the relationship between criteria (Singh et al., 2007a).

The research process followed during the study is visualized in Figure 8.

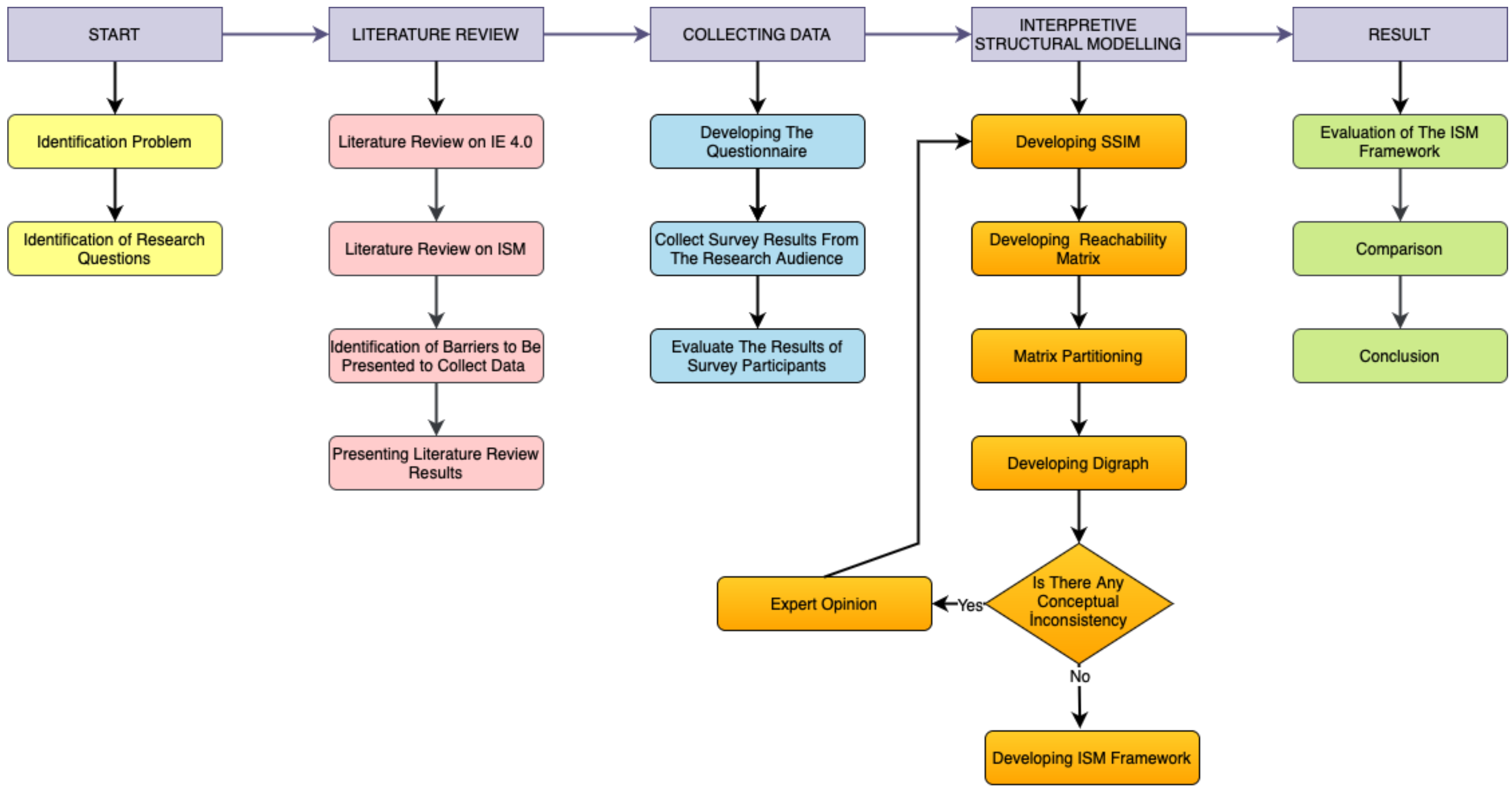

Figure 8: Research Methodology

The general steps of the ISM methodology to be followed during the study are given below. These steps are customized for the subject of interest during the study.

i. Researching the literature, asking expert groups, or determining the variable items about the research as a result of a survey.

ii. Deciding on the contextual relations of the determined variables by examining them in pairs.

iii. Generating the Structural Self-Interaction Matrix (SSIM) in which the binary relationships of the variables are shown.

iv. Creating an initial reachability matrix based on the SSIM table obtained in the previous step. In the ISM methodology, transitivity between variables is assumed. For example, if the X variable has an effect on the Y variable and the Y variable has an effect on the Z variable, it is assumed that the X variable has an effect on the Z variable.

v. Developing the reachability matrix at different levels starting from the initial reachability matrix, creating the final reachability matrix

vi. Creating a Directed graph (Digraph)

vii. Creation of the ISM structure

viii. Evaluation of ISM model results, implementation of changes if needed

The process followed during the use of the ISM methodology for “industrial 4.0 technologies’ adaptation” is explained step by step in Figure 9.

Figure 9: ISM Process

3.1. Data Collection

One of the key elements in this study is the evaluation of the barriers that affect the adaptation of industry 4.0 technologies to the manufacturing sector. At this point, deciding on the barriers to which the ISM method will be applied is one of the critical stages of the research. During the literature search, the active variables in the articles developed in a similar field were brought together by taking note of their sources. After creating the table in which 62 factors are specified, the explanation of each item is detailed. The variable table was narrowed down to 25 items by leaving one of the similar items from the literature. For example, there were articles with the "Cybersecurity issues" barrier (Kamble et al., 2018), (Orzes & Sarkis, 2019). There were studies that included the "Data security and data protection" barrier (M. Sharma et al., 2021). Only "Data security and data protection" was chosen because the two barriers have similar meanings. The same was true for the "Enhanced skill requirement for employees" (Kamble et al., 2018) barrier and the "Need for enhanced skills" (Majumdar et al., 2021) barriers.

The 25 barriers obtained are shown in Table 4.

Table 4: Barriers for industry 4.0

No	Barrier	**Source**(Rajput & Singh, 2019)
1	Workers' resistance	Jadhav et al., 2014
2	Lack of digital culture	Rajput & Singh, 2019
3	Lack of trained staff	Orzes et al., 2019
4	Employment disruption	Raj et al., 2020
5	High implementation cost	Raj et al., 2020
6	Seamless integration and compatibility issues	Raj et al., 2020
7	Poor R&D on industry 4.0 adoption	Ajmera & Jain, 2019
8	Inadequate maintenance support system	Ajmera & Jain, 2019
9	Lack of methodical approach for implementation	Orzes et al., 2019
10	Problem of coordination and collaboration	Luthra & Mangla, 2018

11	Time constraint	Rajput & Singh, 2019
12	Lack of experience in project management and budgeting	Müller, 2019
13	Lack of risk management tools for investments	Ajmera & Jain, 2019
14	Lack of clear apprehension of benefits	Orzes et al., 2019
15	Fear of failure	Kamble et al., 2018
16	Lack of government support and policies	Luthra & Mangla, 2018
17	Compatibility Issues between existing and new systems	Luthra & Mangla, 2018
18	Lack of infrastructure and internet- based networks	Yadav et al., 2020
19	Data security and data protection	Ivanov et al., 2021
20	Lack of standards and reference architectures	Yadav et al., 2020
21	Lack of management dedication, commitment, and leadership	Luthra & Mangla, 2018
22	Lack of futuristic outlook	Govindan et al., 2014
23	Managing employee anxiety	Kamble et al., 2018
24	Undeveloped of social infrastructure	Kamble et al., 2018
25	Regulatory compliance concerning social requirements	Kamble et al., 2018

The descriptions of the barriers selected during the study are as follows:

Workers' resistance: Industry 4.0 technologies will cause changes in job descriptions and processes. Each change will mean that employees will give up their habits. This may cause resistance to industry 4.0 by workers.

Lack of digital culture: It is critical to have a digitalization culture in the production sector in order to adapt to industry 4.0 technologies. Without a culture of digitization, industry

4.0 will be difficult to maintain. The lack of a culture of digitization can be one of the obstacles.

Lack of trained staff: Personnel working in the current situation may be ignorant and untrained on how to use new technologies to be adapted. Trained employees are needed for the implementation of industry 4.0 technologies.

Employment disruption: Thanks to the technologies integrated into the manufacturing factory, some of the tasks can be done without the need for human intervention. This may result in the loss of workers. The concern created by this situation may be one of the barriers in the industry 4.0 adaptation.

High implementation cost: Developing infrastructure for industry 4.0 technologies can result in high implementation costs. This requires high capital.

Seamless integration and compatibility issues: With new technologies, seamless integration between the equipment and network systems is one of the critical issues.

Poor R&D on industry 4.0 adoption: As industry 4.0 is a relatively new field, it is a missing field in research and development. The number of studies evaluating concrete results is limited.

Inadequate maintenance support system: There are no expert maintenance and repair teams in this field yet.

Lack of methodical approach for implementation: There are not enough reference architectures and standards to follow for perfect implementation.

Problem of coordination and collaboration: There is a high risk of hardware and software compatibility issues. Adaptation requires the coordinated work of each stakeholder in the process.

Time constraint: The transition to the new application may cause pauses and delays in production processes. Factories that have very high time constraints in their production may find it difficult to afford it.

Lack of experience in project management and budgeting: It is very difficult for project management to manage cost analysis, budgeting, resource allocation and predicting possible risks during the transition to industry 4.0 technologies.

Lack of risk management tools for investments: Since there are not many application examples, there is no risk management tool to decide the risk amount of investments.

Lack of clear apprehension of benefits: There is a lack of data on the benefits of industry 4.0.

Fear of failure: Since there is not enough concrete data on the success of industry 4.0, entrepreneurs may have thought of failure.

Lack of government support and policies: The fact that the government has not announced a specific policy method on industry 4.0 is one of the obstacles. Having a law restricting industry 4.0 technologies that the government can disclose is a risk.

Compatibility Issues between existing and new systems: It is difficult to manage the transition between the current operating system and the new system to be installed.

Lack of infrastructure and internet-based networks: New technologies require strong internet connection and infrastructure. Their lack is one of the barriers to adaptation.

Data security and data protection: Information about the process in the factory is stored as data along with the digitized process. If the necessary security measures are not taken, this data may fall into the hands of malicious people.

Lack of standards and reference architectures: The absence of global standards, such as data sharing protocols in this area, is an obstacle.

Lack of management dedication, commitment, and leadership: The senior management's belief in industry 4.0 and their encouragement and dedication to this change are critical factors during adaptation. Its absence is a barrier.

Lack of futuristic outlook: Companies should be aware that they are making a move for the future, not the moment. Otherwise, if they do not develop their vision in this direction, it is an obstacle.

Managing employee anxiety: Change can cause anxiety and restlessness in employees. The inability to manage this environment is one of the obstacles.

Undeveloped of social infrastructure: If no contribution is made to the development of the social infrastructure of the team working in the factory in this respect, this will be an obstacle.

Regulatory compliance concerning social requirements: The new order will require new social guidelines. One of the obstacles is the immaturity of yet functioning instructions.

Before the 25 items in Table 4 were presented as inputs to the ISM method, they were presented to people working in the manufacturing sector through a questionnaire to select the most critical items. The questionnaire consists of two different parts. In the first part, the participants scored 25 items in front of adaptation in the production sector using a Likert Scale in the range of 1-5 points. The Likert Scale used during the survey is shown in Table 5. In the second part, they were asked to rank these 25 items from the most critical to the least critical. Ethical approval was obtained from the participants during the survey. The sample of the questionnaire presented to the participants is in Appendix A. Age information, years of experience in working life and gender information were collected from the participants during the survey. In Figure 10, Figure 11 and Figure 12, the profile information of the experts participating in the survey in these criteria is summarized. Their age, gender and years of experience in business life are included in their profile information.

Table 5: Likert Scale

No effect	Less effective	Partially effective	Effective	Too effective
1	2	3	4	5

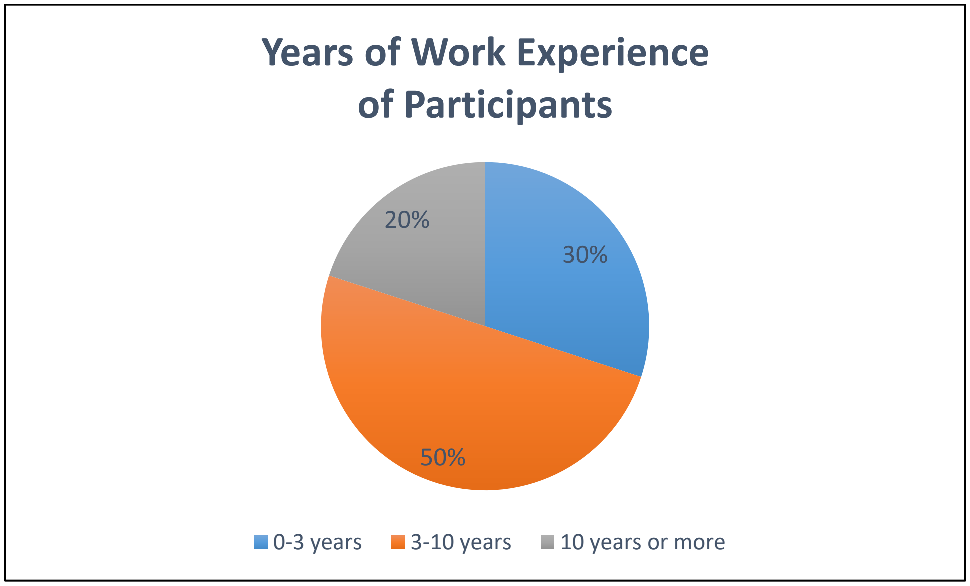

Figure 10: Years of work experience of participants

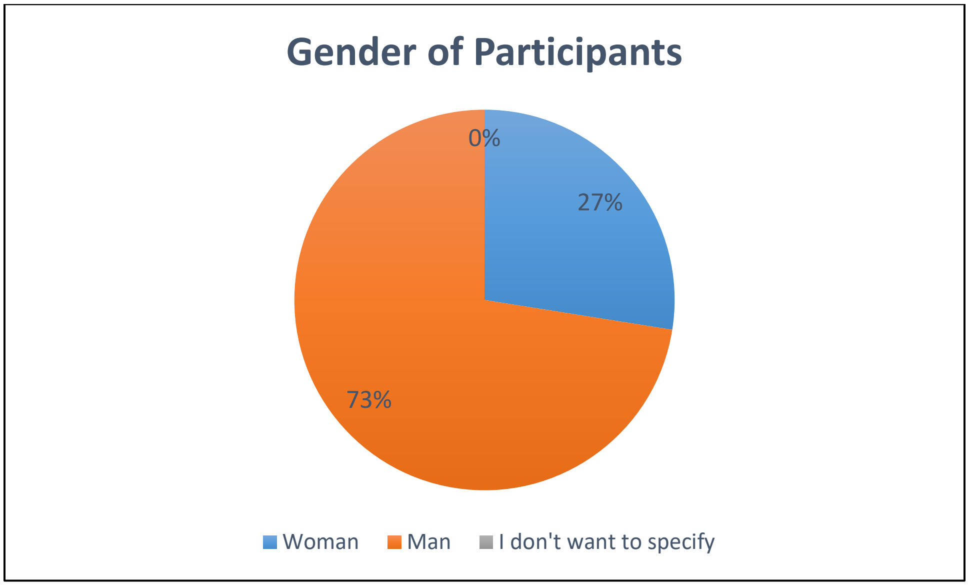

Figure 11: Gender of participants

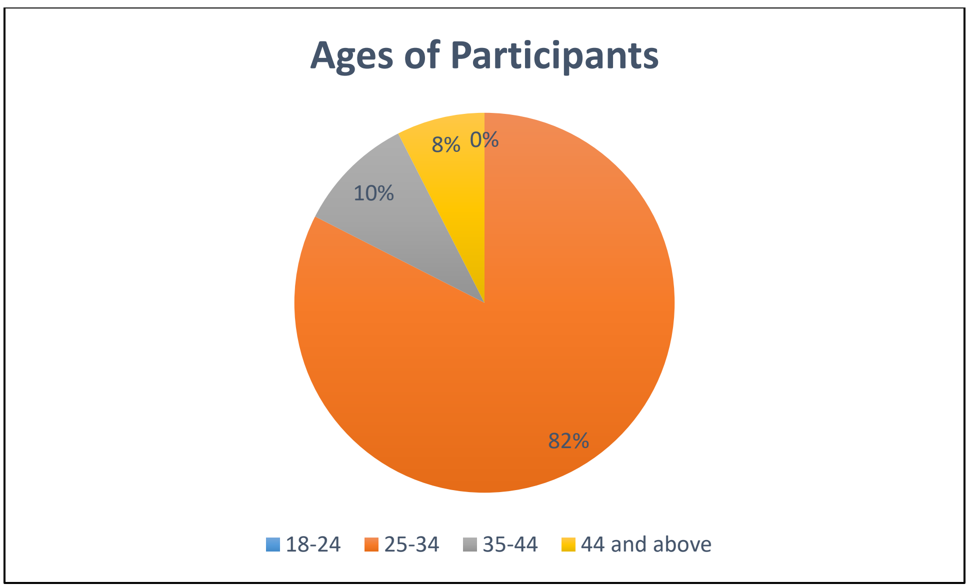

Figure 12: Ages of participants

3.2. The Self-Structural Interaction Matrix

The 25 barriers presented in the questionnaire are ranked in the order of 5 points according to the answers given by the participants. 11 barriers with a score of 3 and above were used in the matrix while developing the self-structural interaction matrix. Barriers selected as a result of this ranking "Workers' resistance - B1", "Lack of digital culture - B2", "Lack of trained staff - B3", "High implementation cost - B4", "Seamless integration and compatibility issues - B5", "Poor R&D on industry 4.0 adoption - B6", "Lack of methodical approach for implementation - B7", "Problem of coordination and collaboration stakeholder - B8", "Lack of clear apprehension of benefits - B9", "Lack of infrastructure and internet-based networks - B10", "Lack of management dedication, commitment, and leadership - B11". In order to facilitate the naming of the barriers during the study, the symbols starting with barriers B are given. The meanings of the expressions V, A, X and O to be used in the matrix are shown in Table 6.

Table 6: Expressions of symbols

Symbol	Explanation
V	There is a forward relationship from Bi to Bj. The Bi barrier acts on the Bj barrier.
A	There is a reverse relationship from Bj to Bi. The Bj barrier acts on the Bi barrier.
X	There is a reciprocal relationship between the Bi and Bj barriers. Both affect each other.
O	There is no relationship between the Bi and Bj barriers.

At this stage, while creating the SSIM, the bilateral relations between the barriers were decided by working with five experts working in the manufacturing sector. Information on the experts worked with is shown in Table 7. The ISM methodology recommends working with a minimum of three experts at this stage.

Table 7: Information of experts

	Years of Work Experience	Working Sector	Company Size by No. of Employees
Expert 1	17	Electronic communication	2000 - 2500
Expert 2	14	Automotive	3000 - 3500
Expert 3	10	White goods manufacturing	4000 - 4500

Expert 4	8	Camera manufacturing	2000 - 2500
Expert 5	4	Defense industry	6000 - 6500

The Self-Structural Interaction Matrix (SSIM), prepared by considering the bilateral relations between the barriers, is shown in Table 8. For example, the managers of a company whose digital culture is not developed will have little faith in the successful implementation of the industry 4.0 revolution. For this reason, the "Lack of digital culture - B2" barrier affects the "Lack of management dedication, commitment, and leadership - B11" barrier. Therefore, "V" is written to the (B2, B11) node. In a company with few trained staff, this employee profile will also negatively affect the company's digital culture. For this reason, the "Lack of trained staff - B3" barrier affects the "Lack of digital culture - B2" barrier. Therefore, in Table 8 (B2, B3) node "A" is written. There is no direct relationship between the "worker resistance – B1" barrier and the "Lack of infrastructure and internet-based networks – B10" barrier. Thus, "O" is written to the (B1, B10) node. In a factory with less worker resistance, stakeholders will be able to work more coordinately. Likewise, the absence of coordination and collaboration problems among stakeholders will reduce workers' resistance to these industry 4.0 changes. Since there is a mutual effect between these two barriers, "X" is written on the (B1, B8) node.

Table 8: The Self-Structural Interaction Matrix SSIM

Barriers		**B11**	**B10**	**B9**	**B8**	**B7**	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**
Workers' resistance	**B1**	A	O	O	X	O	O	X	O	A	A	
Lack of digital culture	**B2**	V	O	V	O	O	X	V	O	A		
Lack of trained staff	**B3**	O	O	V	V	O	O	V	O			
High implementation cost	**B4**	O	A	O	O	O	O	O				
Seamless integration and compatibility issues	**B5**	O	A	O	O	A	A					
Poor R&D on industry 4.0 adoption	**B6**	A	O	V	O	V						

Lack of methodical approach for implementation	**B7**	O	O	O	O
Problem of coordination and collaboration stakeholder	**B8**	A	O	A	
Lack of clear apprehension of benefits	**B9**	A	O		
Lack of infrastructure and internet-based networks	**B10**	O			
Lack of management dedication, commitment, and leadership	**B11**				

3.3. Reachability Matrix

The self-structural interaction matrix obtained is converted into a binary matrix at this stage. V, A, X, and O expressions in SSIM take the values 1 or 0 depending on their meaning. This change in the table is made according to the following rule:

- If the symbol V from barrier i to barrier j is used in the SSIM matrix, point (i, j) takes the value 1, while point (j, i) takes the value 0.

- If the symbol A from barrier i to barrier j is used in the SSIM matrix, point (i, j) takes the value 0, while point (j, i) takes the value 1.

- If the X symbol from barrier i to barrier j is used in the SSIM matrix, point (i, j) takes the value 1, while point (j, i) takes the value 1.

- If the symbol O from barrier i to barrier j is used in the SSIM matrix, point (i, j) takes the value 0, while point (j, i) takes the value 0.

The relationship used when converting to Binary is shown in Table 9.

Table 9: Binary matrix conversion expressions

i, *j* record in SSIM	V	A	X	O
i, *j* record in the initial reachability matrix	1	0	1	0
j, *i* record in the final reachability matrix	0	1	1	0

The initial reachability matrix in table 10 was obtained by converting the values in the SSIM matrix into binary values by considering the method in table 9.

Table 10: Initial Reachability Matrix

Barriers		**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**
Workers' resistance	**B1**	1	0	0	0	1	0	0	1	0	0	0
Lack of digital culture	**B2**	1	1	0	0	1	1	0	0	1	0	1
Lack of trained staff	**B3**	1	1	1	0	1	0	0	1	1	0	0
High implementation cost	**B4**	0	0	0	1	0	0	0	0	0	0	0
Seamless integration and compatibility issues	**B5**	1	0	0	0	1	0	0	0	0	0	0
Poor R&D on industry 4.0 adoption	**B6**	0	1	0	0	1	1	1	0	1	0	0
Lack of methodical approach for implementation	**B7**	0	0	0	0	1	0	1	0	0	0	0
Problem of coordination and collaboration stakeholder	**B8**	1	0	0	0	0	0	0	1	0	0	0
Lack of clear apprehension of benefits	**B9**	0	0	0	0	0	0	0	1	1	0	0
Lack of infrastructure and internet-based networks	**B10**	0	0	0	1	1	0	0	0	0	1	0
Lack of management dedication, commitment, and leadership	**B11**	1	0	0	0	0	1	0	1	1	0	1

According to the transitivity assumption, if the A barrier is effective on the B barrier and the B barrier is also effective on the C barrier, the A barrier also has an effect on the C barrier. Based on the transitivity assumption, the final reachability matrix in Table 11 was obtained from the initial matrix in Table 10.

The driver power and dependency information of the barriers are included in the final reachability matrix. Driving power was obtained by summing the binary values of each barrier in the row, and dependency information was obtained by summing the binary column values of each barrier. The driving force for each barrier is the total number of barriers it has an effect on, including itself. The dependency for each barrier indicates the extent to which that barrier is affected by other barriers. (Singh et al., 2007a)

Table 11: Final Reachability Matrix

		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	Driver Power
Workers' resistance	**B1**	1	0	0	0	1	0	0	1	0	0	0	3
Lack of digital culture	**B2**	1	1	0	0	1	1	1	1	1	0	1	8
Lack of trained staff	**B3**	1	1	1	0	1	1	1	1	1	0	1	9
High implementation cost	**B4**	0	0	0	1	0	0	0	0	0	0	0	1
Seamless integration and compatibility issues	**B5**	1	0	0	0	1	0	0	1	0	0	0	3
Poor R&D on industry 4.0 adoption	**B6**	1	1	0	0	1	1	1	1	1	0	1	8
Lack of methodical approach for implementation	**B7**	1	0	0	0	1	0	1	1	0	0	0	4
Problem of coordination and collaboration stakeholder	**B8**	1	0	0	0	1	0	0	1	0	0	0	3
Lack of clear apprehension of benefits	**B9**	1	0	0	0	1	0	0	1	1	0	0	4
Lack of infrastructure and internet-based networks	**B10**	1	0	0	1	1	0	0	1	0	1	0	5
Lack of management dedication, commitment, and leadership	**B11**	1	1	0	0	1	1	1	1	1	0	1	8
	Dependency	10	4	1	2	10	4	5	10	5	1	4	56

3.4. Level Partitioning

In this step of the ISM method, the reachability set, antecedent set and intersection set of each barrier are found based on the final reachability matrix. Reachability set is the set of barriers that can be reached by starting from the barrier, including the barrier itself. The antecedent set consists of other barriers that affect it, including the barrier itself. An intersection set is a set of barriers that are simultaneously present in the reachability set and the antecedent set.

After the sets are created, the barriers are separated according to the ISM layers. Barriers with the same values in the reachability set and intersection set are the highest-level barrier in the ISM layer. Top-level barriers in ISM layers do not affect a barrier at a different level after it. In this way, the first table is created. After the 1st level barriers are decided, these barriers are removed from the table and the same process is repeated. The first information, including the reachability set, antecedent set and intersection sets, are shown in Table 12. Table 12 shows that “Workers’ resistance - B1”, “High implementation cost - B4”, “Seamless integration and compatibility issue - B5” and “Problem of coordination and collaboration stakeholder - B8” constitute the first level of ISM.

Table 12: Iteration 1 for ISM

Barrier	**Reachability Set**	**Antecedent set**	**Intersection set**	**Level**
B1	B1, B5, B8	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11	B1, B5, B8	1
B2	B1, B2, B5, B6, B7, B8, B9, B11	B2, B3, B6, B11	B2, B6, B11	
B3	B1, B2, B3, B5, B6, B7, B8, B9, B11	B3	B3	
B4	B4	B4, B10	B4	1
B5	B1, B5, B8	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11	B1, B5, B8	1
B6	B1, B2, B5, B6, B7, B8, B9, B11	B2, B3, B6, B11	B2, B6, B11	

B7	B1, B5, B7, B8	B2, B3, B6, B7, B9	B7	
B8	B1, B5, B8	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11	B1, B5, B8	1
B9	B1, B5, B8, B9	B2, B3, B6, B9, B11	B9	
B10	B1, B4, B5, B8, B10	B10	B10	
B11	B1, B2, B5, B6, B7, B8, B9, B11	B2, B3, B6, B11	B2, B6, B11	

While starting the second iteration, the barriers determined as Level 1 were removed from the table. In the 2nd iteration, it was observed that the "Lack of methodical approach for implementation - B7", "Lack of clear apprehension of benefits - B9" and "Lack of infrastructure and internet- based networks - B10" barriers were Level 2. The second iteration is shown in Table 13.

Table 13: Iteration 2 for ISM

Barrier	Reachability Set	Antecedent set	Intersection set	Level
B2	B2, B6, B7, B9, B11	B2, B3, B6, B11	B2, B6, B11	
B3	B2, B3, B6, B7, B9, B11	B3	B3	
B6	B2, B6, B7, B9, B11	B2, B3, B6, B11	B2, B6, B11	
B7	B7	B2, B3, B6, B7, B9	B7	2
B9	B9	B2, B3, B6, B9, B11	B9	2
B10	B10	B10	B10	2
B11	B2, B6, B7, B9, B11	B2, B3, B6, B11	B2, B6, B11	

While passing to Iteration 3, the barriers determined as Level 2 were removed from the table. In Iteration 3, "Lack of digital culture - B2", "Poor R&D on industry 4.0 adoption -

B6" and "Lack of management dedication, commitment, and leadership - B11" were identified as Level 3 barriers. Iteration 3 is shown in Table 14.

Table 14: Iteration 3 for ISM

Barrier	Reachability Set	Antecedent set	Intersection set	Level
B2	B2, B6, B11	B2, B3, B6, B11	B2, B6, B11	3
B3	B2, B3, B6, B11	B3	B3	
B6	B2, B6, B11	B2, B3, B6, B11	B2, B6, B11	3
B11	B2, B6, B11	B2, B3, B6, B11	B2, B6, B11	3

Level 3 barriers are removed from the table before proceeding to the last iteration. In the last iteration, only the "Lack of trained staff – B3" barrier remained in the table. This barrier is marked as a Level 4 barrier. The details of the iteration are given in Table 15.

Table 15: Iteration 4 for ISM

Barrier	Reachability Set	Antecedent set	Intersection set	Level
B3	B3	B3	B3	4

After the iterations are completed, the barriers according to their levels are shown in Table 16.

Table 16: Levels of barriers

Level 1	B1 (Workers' resistance), B4 (High implementation cost), B5(Seamless integration and compatibility issues), B8(Problem of coordination and collaboration stakeholder)

Level 2	B7(Lack of methodical approach for implementation), B9(Lack of clear apprehension of benefits), B10(Lack of infrastructure and internet- based networks)
Level 3	B2(Lack of digital culture), B6(Poor R&D on industry 4.0 adoption), B11(Lack of management dedication, commitment, and leadership)
Level 4	B3(Lack of trained staff)

3.5. The classification of the barriers

According to the driver power and dependency scores in Table 11, barriers can be evaluated in 4 different categories. These categories are Drivers, Linkage, Autonomous and Dependent. The characteristics of each category are summarized in Table 17. The purpose of this classification of barriers is to analyze the dependency and driving power characteristics of the barriers. In this analysis, the barriers are placed on the coordinate plane according to the driving power and dependency information. Figure 13 was created as a result of this step.

Table 17: Characteristics of categories

Category	**Autonomous**	**Dependent**	**Linkage**	**Drivers**
Properties	Weak driving power Weak dependence	Weak driving power Strong dependency	Strong driving power Strong dependency	Strong driving power Weak dependence

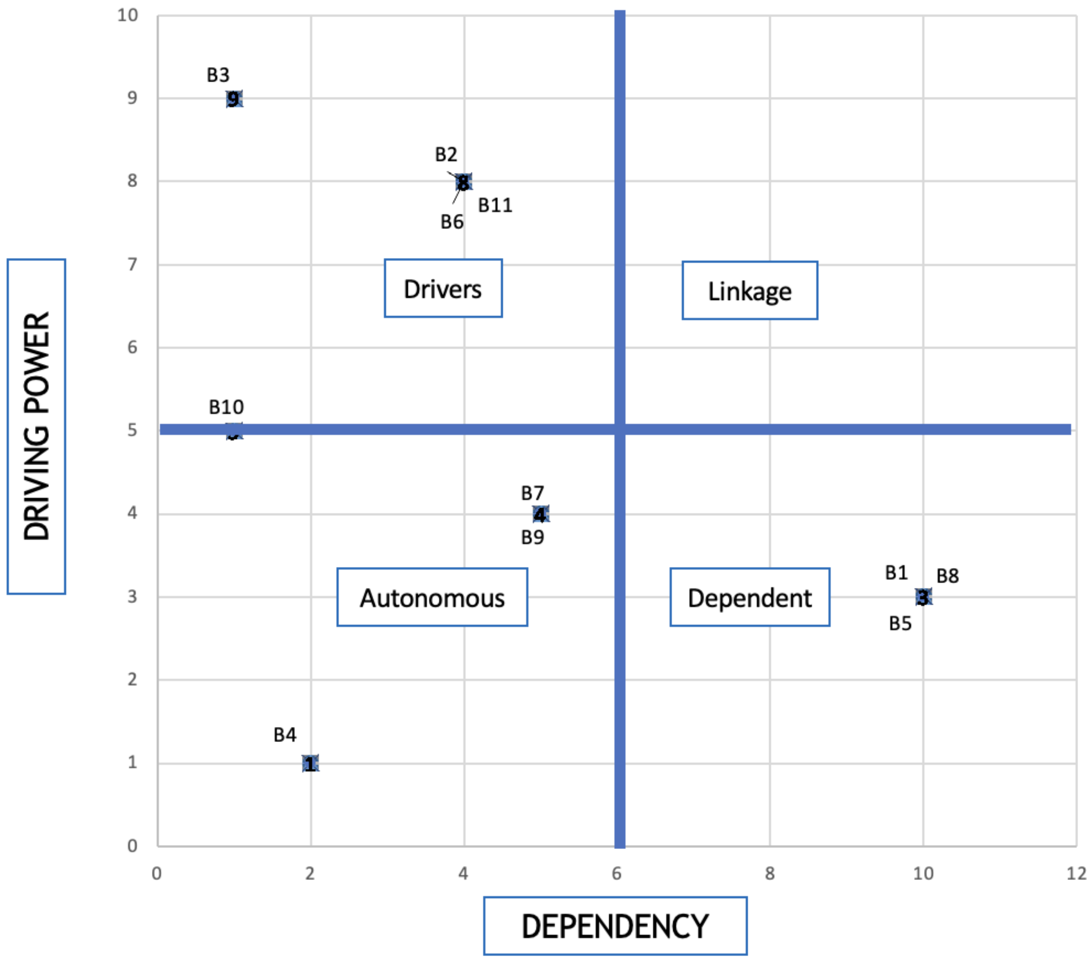

Figure 13: MICMAC analysis of barriers

Autonomous barriers in the first quadrant are relatively unrelated to other barriers in the system. In this respect, "High implementation cost - B4" has a low score in terms of both driving power and dependency. While the barriers of "Workers' resistance – B1", "Seamless integration and compatibility issues – B5" and "Problem of coordination and collaboration stakeholder – B8" in the second "Dependent" quadrant are high in terms of dependency, they are low in terms of driving power. These barriers are equal in this analysis in terms of both dependency and driving power score. In this study, there is no barrier that has the characteristics of the "Linkage" part of the 3rd quadrant. 4. In the Quadrant Drivers section, the "Lack of digital culture – B2", "Poor R&D on industry 4.0 adoption – B6", and "Lack of management dedication, commitment, and leadership – B11" barriers are at the same point. The driving power and dependency scores of the B2, B6 and B11 barriers are the same. The "Lack of trained staff – B3" barrier in this quadrant has a relatively lower dependency and higher driving power. The “Lack of infrastructure and internet-based networks – B10” barrier is located between the Autonomous and Drivers quadrants, while the driving power is at a medium level, the dependency score is relatively low.

3.6. ISM Framework

It will be useful to examine the overall level partition before creating an ISM framework. The overall level partition for barriers is shown in Table 18.

Table 18: Overall level partition for barriers

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
B1	B1, B5, B8	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11	B1, B5, B8	1
B2	B1, B2, B5, B6, B7, B8, B9, B11	B2, B3, B6, B11	B2, B6, B11	3
B3	B1, B2, B3, B5, B6, B7, B8, B9, B11	B3	B3	4
B4	B4	B4, B10	B4	1
B5	B1, B5, B8	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11	B1, B5, B8	1
B6	B1, B2, B5, B6, B7, B8, B9, B11	B2, B3, B6, B11	B2, B6, B11	3
B7	B1, B5, B7, B8	B2, B3, B6, B7, B9	B7	2
B8	B1, B5, B8	B1, B2, B3, B5, B6, B7, B8, B9, B10, B11	B1, B5, B8	1
B9	B1, B5, B8, B9	B2, B3, B6, B9, B11	B9	2
B10	B1, B4, B5, B8, B10	B10	B10	2
B11	B1, B2, B5, B6, B7, B8, B9, B11	B2, B3, B6, B11	B2, B6, B11	3

A directed graph is created based on the analysis data in Table 11 and Table 18 obtained at this stage. The direction of the arrows is decided according to the relations between the barriers. For example, since Barrier 3 has an effect on Barrier 1, the arrow coming out of node 3 is directed to node 1. The pairwise relationships obtained according to the transitivity law in ISM are shown with dot lines. Proceeding in this way, Figure 14 was obtained. The resulting Figure 14 shows that we are dealing with a very complex problem to understand. In the next step, Figure 15 was obtained by developing the directed graph considering the levels of the barriers obtained by the ISM method. Level 1 barriers are placed at the top and level 2 barriers are placed below level 1 barriers. In the same order, the 3rd-level barriers are placed under the 2nd-level barriers, followed by the 4th-level barrier, Barrier 3, at the bottom.

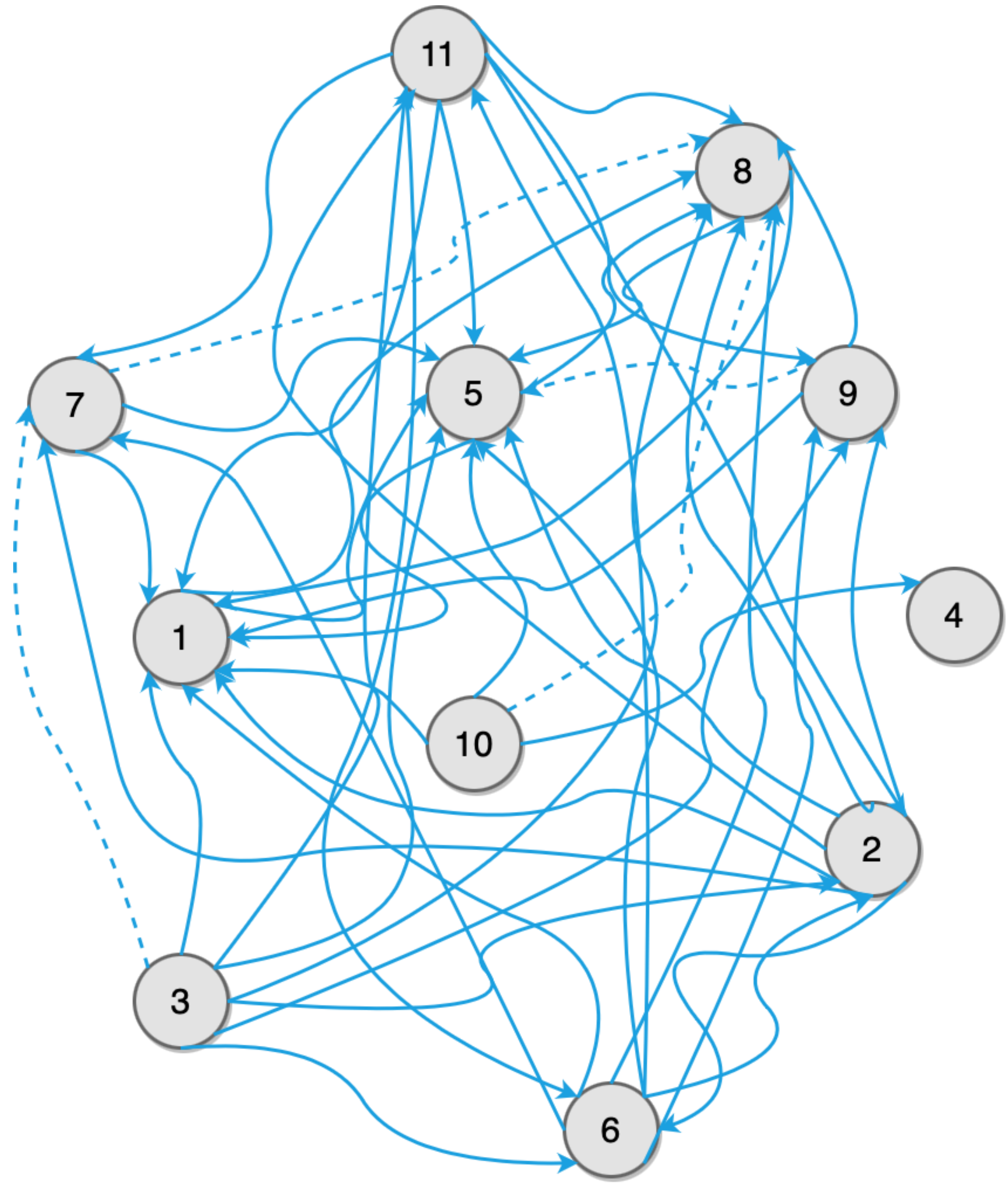

Figure 14: Initial digraph

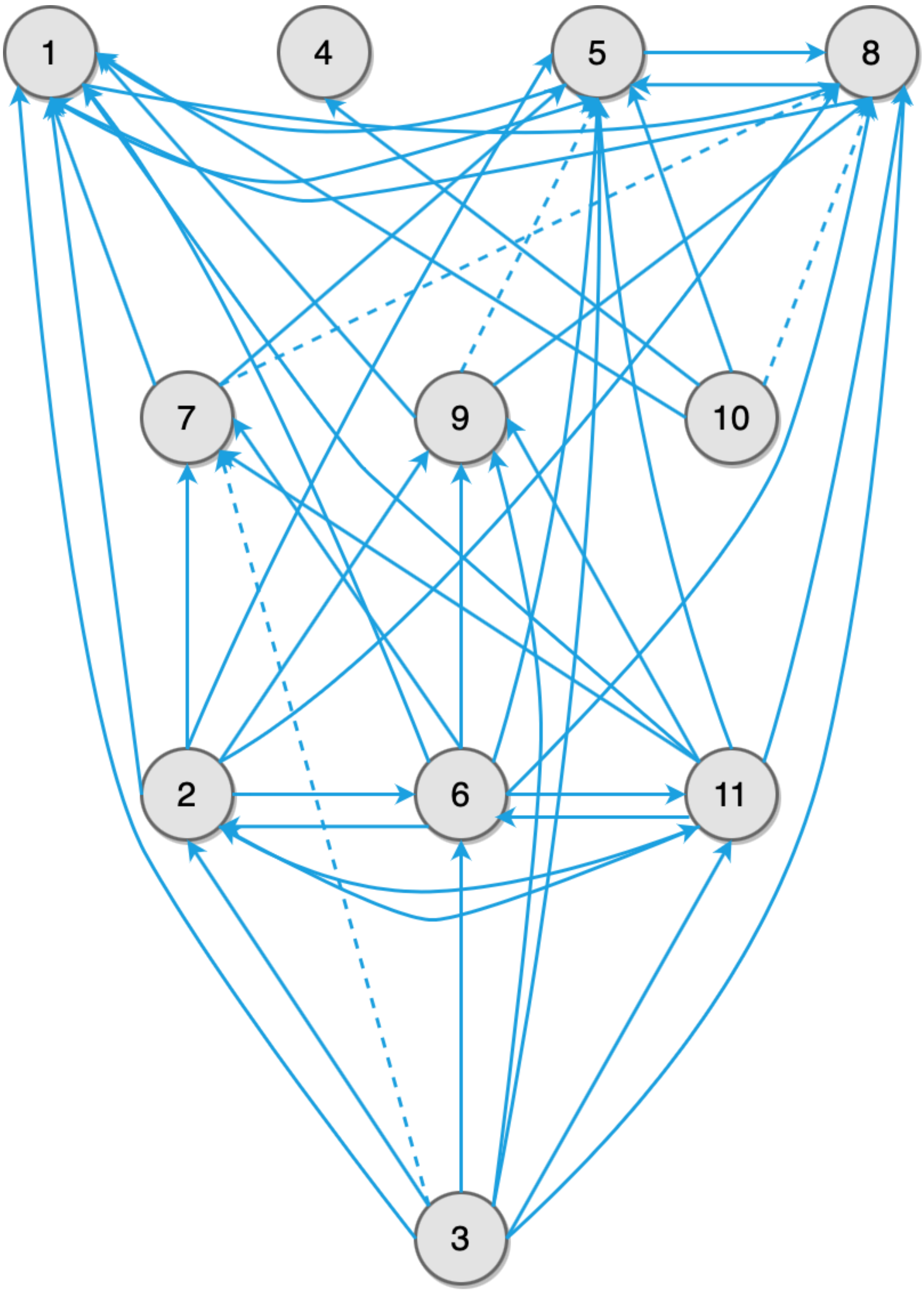

Figure 15: Directed graph by the level of barriers

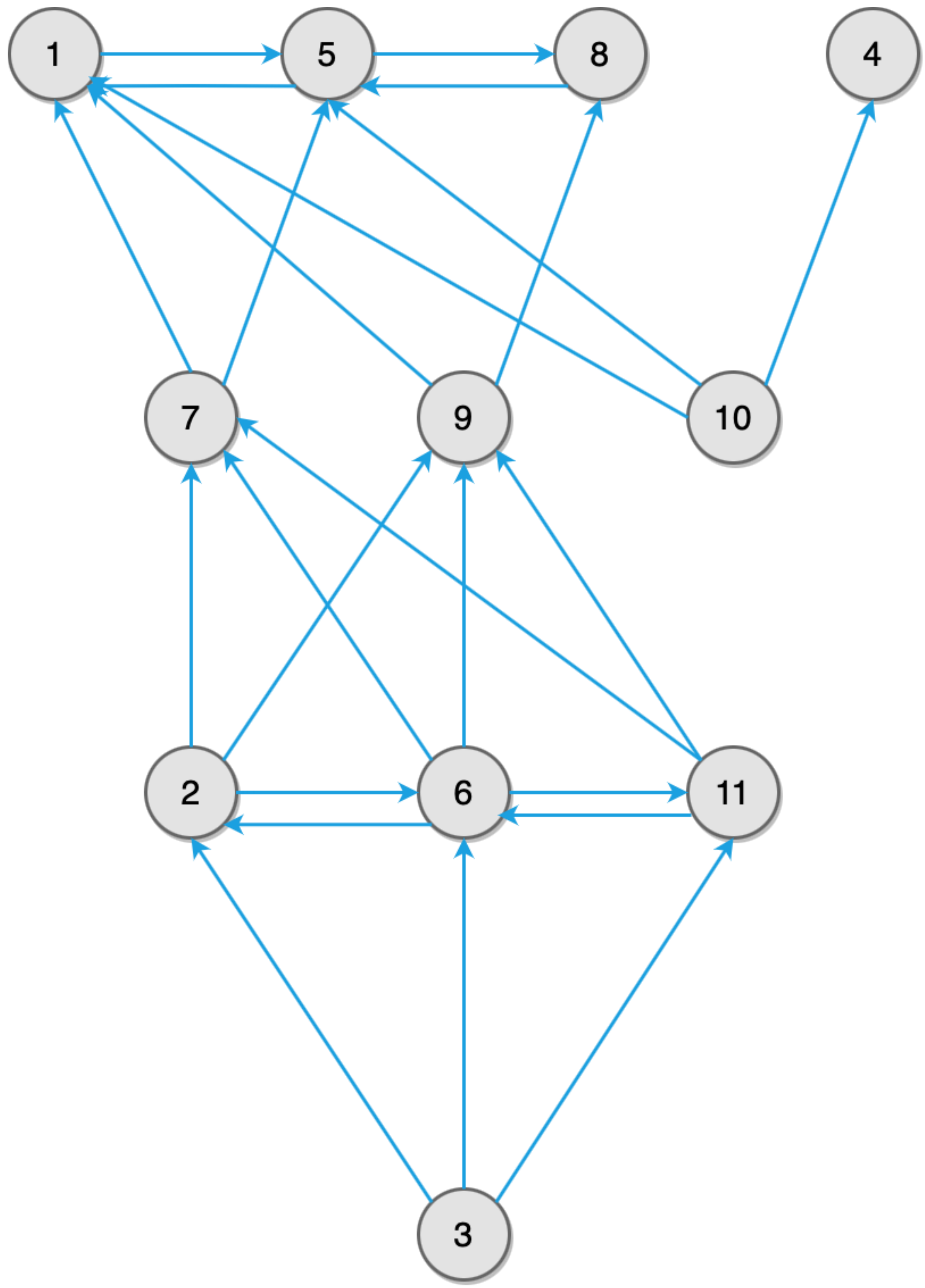

Figure 16: Final directed graph (digraph)

Based on the final digraph, the ISM structure model is developed. The arrows from the i barrier to the j barrier in the ISM framework indicate a relationship between the i and j barriers. While obtaining the ISM framework, the barriers they express are written instead of the nodes in the final digraph. The resulting ISM framework is shown in Figure 17. The "Lack of trained staff" barrier is located at the bottom of the framework. Other barriers are placed above this barrier. This means that the "Lack of trained staff" barrier affects all other barriers. It can also be stated that "lack of trained staff" is the most basic barrier in this working group. The barriers to "Lack of digital culture", "Poor R&D on industry 4.0 adoption" and "Lack of management dedication, commitment, and leadership" are at the next level. These barriers also affect each other. "Lack of methodical approach for implementation", "Lack of clear apprehension of benefits" and "Lack of infrastructure and internet-based networks" barriers are at a higher level. At the top of the ISM framework are the "Workers' resistance", "High implementation cost, "Seamless integration and compatibility issues" and "Problem of coordination and collaboration stakeholder" barriers. In the resulting model, these barriers, which are at the top, have relatively less effect on other barriers.

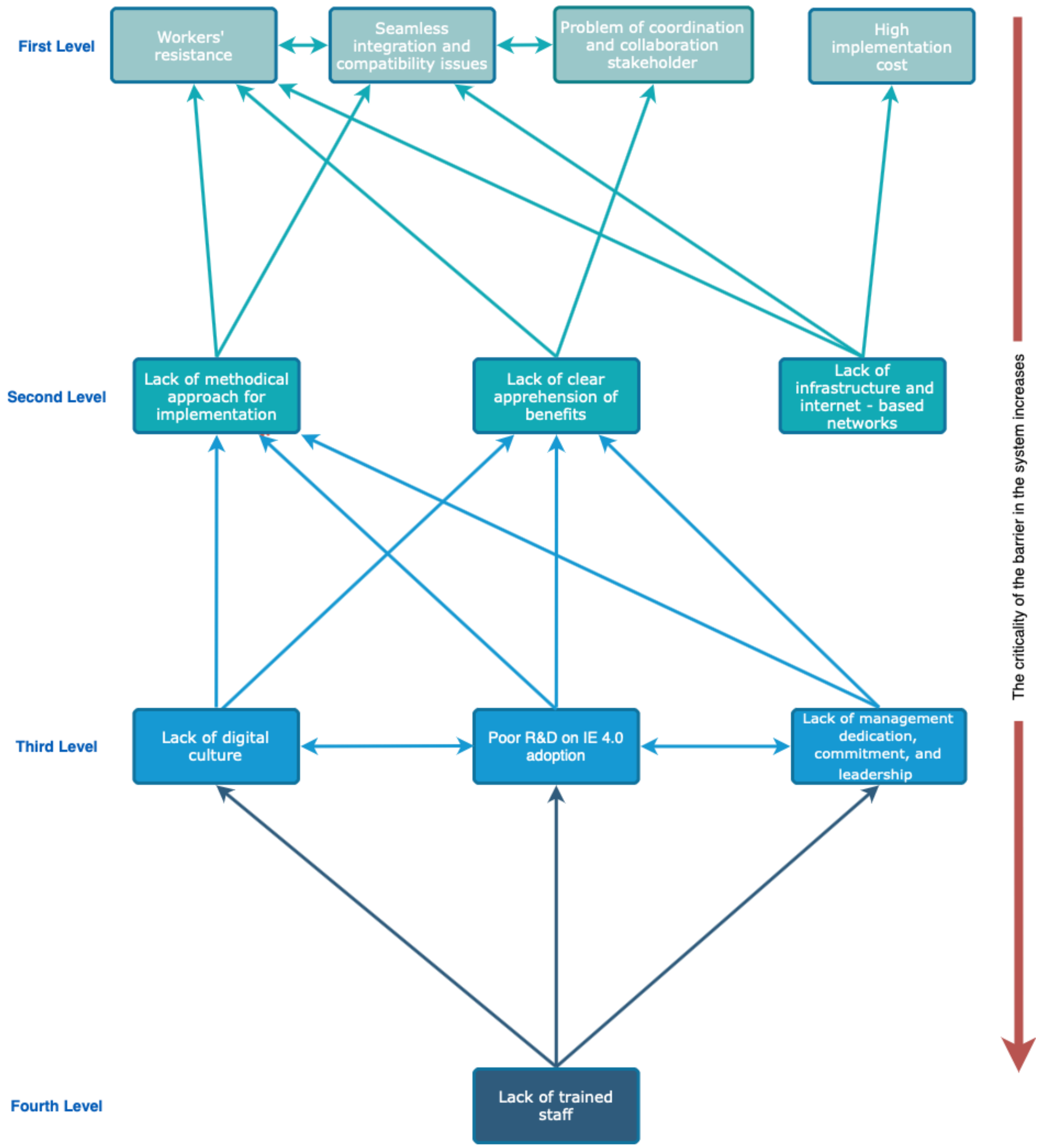

Figure 17: ISM Framework

4. RESULTS AND COMPARISONS

At this stage, it would be useful to compare the results of the study with other studies in the literature.

The study carried out by Rajesh K. Singh and Suresh K. Garg was progressed by consulting six experts. 13 factors are presented as inputs to the ISM methodology. While the “Top management commitment” of the study conducted in India was the most critical influencing factor, “Employees’ training and participation” was determined as the second most critical factor. While employee training was the most critical factor in our study, the commitment of the management to this change was identified as the second most critical factor (Singh et al., 2007b). The ISM framework obtained as a result of the related study is shown in Figure 18.

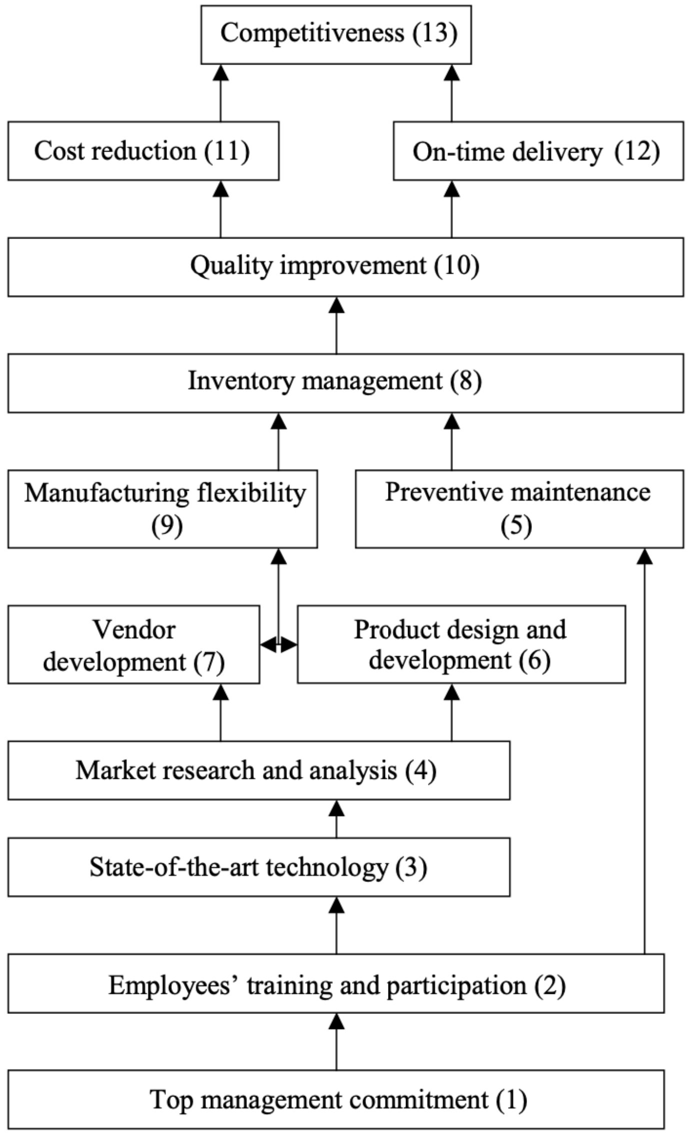

Figure 18: The ISM framework obtained according to the work carried out by Rajesh K. Singh and Suresh K. Garg. (The figure is taken from the main source.) (Singh et al., 2007b)

The study by Srijit Krishnan and Sumit Gupta examined the I4.0 adaptation in the Indian Automobile Industry. Based on the questionnaire responses from 32 people, ten enablers were presented as input to the ISM methodology. In this study, "Top management interest towards implementing I4.0", "Government policies to support a smart factories" and "Financial Performance" emerged as the first three levels. In this study, the staff profile was not presented to the participants as a factor (Krishnan et al., 2021b). The ISM framework obtained as a result of the related study is shown in Figure 19.

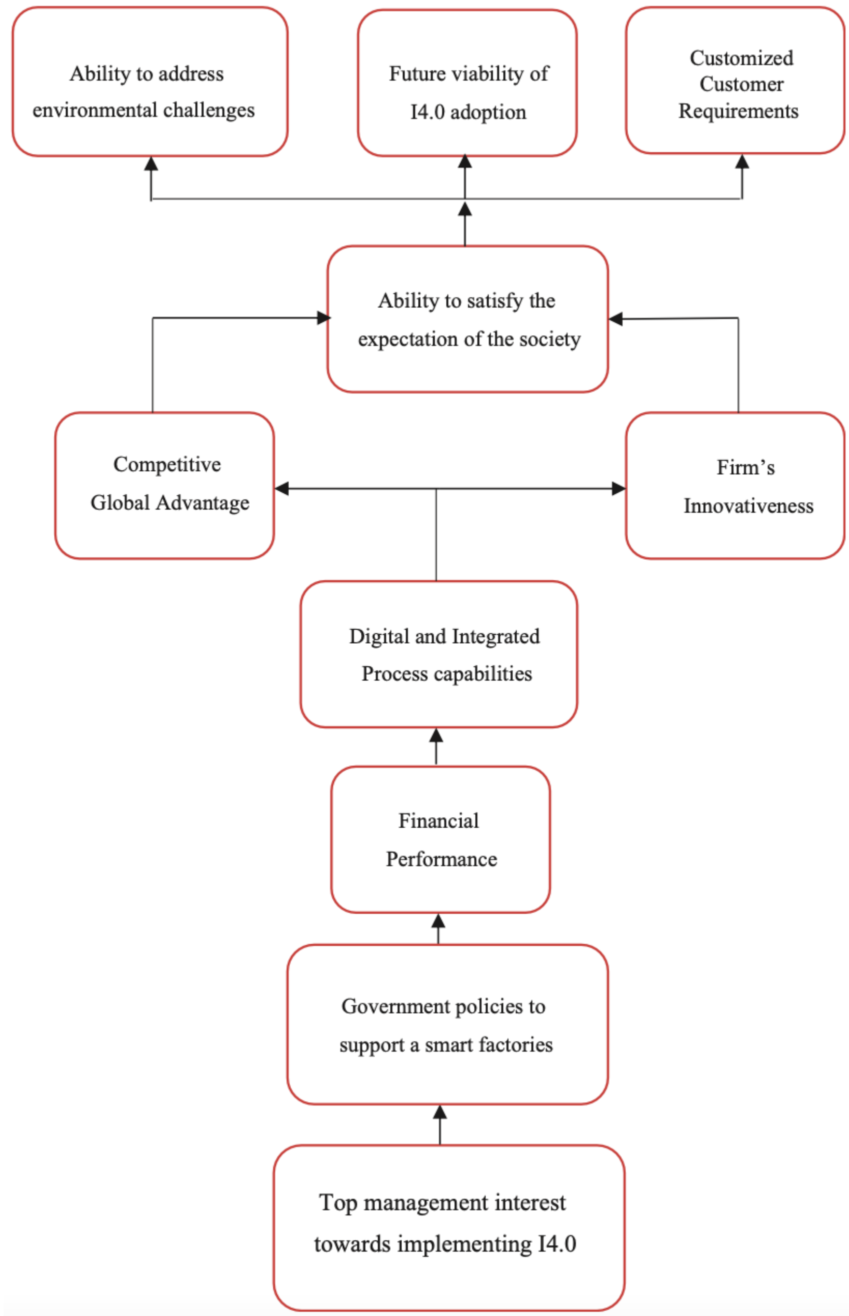

Figure 19: The ISM framework obtained according to the work carried out by Srijit Krishnan and Sumit Gupta. (The figure is taken from the main source.)(Krishnan et al., 2021b)

In the study conducted by Saliha Karadayı, interpretive structural analysis and industry 4.0 adoption challenges were examined without any sector privatization. In order to identify the conceptual relationship between the barrier couples, two experts from Bosch

Industry 4.0 project group and an academician giving a lesson about industry 4.0 are asked for advice.

As a result of the study, a four-level ISM framework was obtained. According to the results of the study, the most critical challenge was determined as a “Lack of advanced education system for training the personnel”. The challenge in the same sense as the most critical item in our findings was the most critical challenge. The “management understanding” challenge, which was the most critical item in the previous study, was not presented to the ISM as input. The selection of experts in this study was in this direction. The ISM framework obtained as a result of the related study is shown in Figure 20.

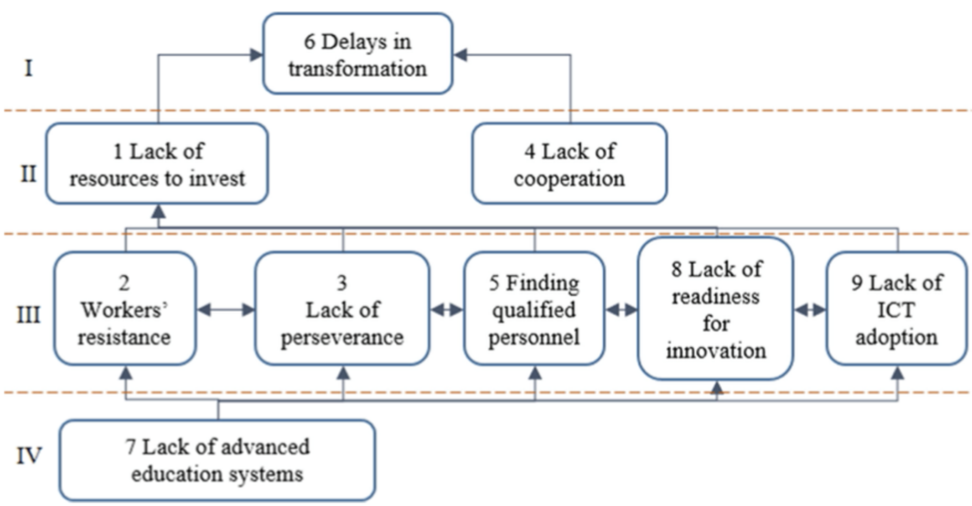

Figure 20: The ISM framework obtained according to the work carried out by Saliha Karadayı. (The figure is taken from the main source.) (Saliha Kara Usta, 2020)

The effect of working with five experts in the framework obtained as a result of the study is very high. When the ISM framework is compared with the results of the survey conducted with 40 participants, remarkable results emerge. When the survey results are ranked on a 5-point scale, the first barriers are listed as “workers’ resistance”, “high implementation cost”, “lack of trained staff” and “lack of digital culture” from the most effective to the least effective. Survey participants evaluated each barrier on its own. The effect of barriers on each other was not taken into account in the survey. One of the critical benefits of the ISM method is that it considers the dyadic relationships of active ingredients. The two barriers “workers’ resistance” and “high implementation cost”, chosen as having the highest impact in the survey results, are Level 1 barriers for the ISM framework.

While the "Lack of management dedication, commitment, and leadership" barrier may appear as the most critical barrier when we look at other studies in the literature, it appears as the 3rd level barrier in this thesis study. The positions of the experts working together in the ISM method in their business life can be effective in the relations between the barriers. If more experts had been consulted in the manager position in this study, the "Lack of management dedication, commitment, and leadership" barrier could have emerged as a 4th Level barrier.

5. CONCLUSION

The use of the industry 4.0 revolution in the manufacturing sector increases the added value of the processes for the company, increases their productivity, provides an advantage in market competition, opens new business opportunities and at the same time ensures the optimized use of energy. These mentioned advantages are just some of the industry 4.0 advantages detailed throughout this paper. In the adaptation process of this industrial revolution; manufacturing methodologies change; infrastructure works are carried out; technologies such as big data, cloud and IoT are integrated into the system; technologically skilled workers are needed.

The purpose of this article can be listed as follows:

- To explain the industry 4.0 revolution in detail.
- Identify critical barriers that emerged during the industry 4.0 adoption in the manufacturing sector.
- Evaluating the relationship between the barriers obtained as a result of the study, based on expert opinions, and creating a hierarchical structure if possible.
- To perform the analysis of the resulting hierarchical structure.

In the first part of the study, the emergence of the industry 4.0 revolution is included. Examples of policies followed by countries in this revolution that took place around the world are given. The benefits of industry 4.0 technologies in the manufacturing sector are mentioned. Industry 4.0 characteristics are specified.

The second part includes the literature review on industry 4.0. The literature research part was carried out in 7 different parts. 9 of the industry 4.0 technologies are explained in detail; The effects of industry 4.0 on manufacturing were mentioned; Information about the sectors and factories where it is applied was shared and examples were given; The driving forces and barriers for industry 4.0 identified in other studies are shown; and finally, industry 4.0's strength, weakness, opportunities and threats information in four categories were revealed by SWOT analysis.

In the methodology part, Interpretive Structural Modeling (ISM) method was used to realize the purpose of this study. The ISM method is used to establish relationships between different components that affect a system and to create a hierarchical framework. The 62 barriers obtained in the literature search section were reduced to 25 barriers by removing similar expressions. These 25 barriers are available to people working in the manufacturing industry. According to the survey results, 11 barriers above the mean were moved to the self-structural interaction matrix. With the study carried out with five experts with different working experiences in the manufacturing sector, bilateral relations between these barriers were determined. The final reachability matrix was obtained from SSIM by proceeding with the transitivity assumption of the ISM method. Level partitioning is done by using the final reachability matrix. In this way, 11 barriers were revealed at four different levels. The developed model reveals the hierarchical relationship between barriers. Figure 17 shows the developed model.

According to the results of the study, “Lack of trained personnel - B3” is the biggest obstacle to the adaptation of the industry 4.0 revolution to the manufacturing sector. It can be thought of as a root barrier that has an effect on other barriers. It is located at the 4th level of the developed model, and since it is located at the bottom of the model, it affects the obstacles at other levels. Industry 4.0 technologies need trained employees in this regard. This will certainly be one of the most critical barriers in an organization where employee training is not sufficient. This barrier will prevent the fundamental adoption of change. I4.0 adaptation, which the foundation of the organization cannot adapt, will not be reflected throughout the organization.

“Lack of methodical approach for implementation - B7”, “Lack of clear apprehension of benefits - B9” and “Lack of infrastructure and internet-based networks - B10” barriers emerged as Level 2 barriers. These three barriers are in the middle of impact criticality. According to the model, “the lack of infrastructure and the internet-based network - B10” barrier is not affected by other barriers.

“Lack of digital culture - B2”, “Poor R&D on Industry 4.0 adoption - B6” and “Lack of management dedication, commitment, and leadership - B11” emerged in the ISM framework as Level 3 barriers. The cultures of organizations are very important in the functioning of the workplace. In general, the culture that develops over time in line with the vision and mission determined during the establishment of the organization becomes a difficult element to change after a while in the company. In this context, the high digital culture of the organization will be one of the facilitators in the adaptation process. Top management is directly responsible for decisions in the manufacturing plant and has a critical influence on the direction the organization will move forward.

“Worker resistance - B1”, “High implementation cost - B4”, “Flawless integration and compliance issues - B5” and “Stakeholder coordination and collaboration issue - B8” emerged as directed barriers most affected by other barriers. These obstacles have a limited effect on other obstacles and are not reflected in the model on other barriers.

During the adaptation of industry 4.0 technologies, it is very critical that employees are trained in this regard. The cultural structure of a company consisting of untrained personnel will be far from digital culture. Untrained personnel will see that they bring industry 4.0 technologies as a risk and will be able to resist. As the education level rises, both the skills of the employees will increase and the adaptation to industry 4.0 will be easier. In this respect, managers who want to benefit from the advantages of the industry 4.0 revolution should choose people who have been trained as their employee profile and train their existing staff. The payoff from government and manufacturing collaboration for education will be huge in a positive way (Majumdar et al., 2021). The beginning of education before business life, the inclusion of industry 4.0 innovations in the curricula will play a role in the adoption of the industry 4.0 revolution by society in general.

In this context, managers who want to implement industry 4.0 should try to remove the obstacles starting from the most effective one, starting from the framework in the model.

The barriers or the effects of the barriers in each sector may be different. In this context, this study is specific to the manufacturing sector. The studies here can guide factories in the manufacturing sector around the world. Especially in the adaptation of industry 4.0 technologies, the culture of the region where the applications will be carried out together with the sector is also very critical. When evaluated in terms of culture, it is seen that the studies in this field in the Turkish manufacturing sector are limited. This study is unique in that it sheds light on the industry 4.0 adaptation to the manufacturing sector in Turkey.

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APPENDICES

APPENDIX A

SURVEY QUESTIONNAIRE

Since the survey was conducted in Turkey, the survey was originally in Turkish. It has been translated into the thesis language while being added to the thesis work.

ANALYSIS OF INDUSTRIAL 4.0 TECHNOLOGIES' ADAPTATION USING INTERPRETIVE STRUCTURAL MODELLING: EMPIRICAL FINDINGS FROM MANUFACTURING SECTOR IN TURKEY

This questionnaire was created to collect data for the thesis research on Information Systems "Analysis of Industrial 4.0 Technologies' Adaptation Using Interpretive Structural Modelling: Empirical Findings From Manufacturing Sector In Turkey".
Participation in the survey is completely voluntary.
There is no time limit to complete.
Personal information of the participants will not be used anywhere.
If you encounter any situation that makes you uncomfortable during the survey, you can leave at any time.

If you agree to participate in the research, you are expected to score 25 factors that are thought to have an impact during the adaptation of İndustry 4.0 technologies obtained as a result of literature research, and then rank them from the most influencing to the least influencing. The work is expected to take approximately 10 minutes.

If you want to express your opinion or ask a question about any subject related to the research, you can contact the researcher via omer.ozturk@metu.edu.tr e-mail address.

Thank you very much for your contribution by participating in the survey.

I have read the above information and participate in this study completely voluntarily.

- Yes
- No

SECTION 1: Participant information

How many years of working experience do you have?

- 0-3 years
- 3-10 years
- 10 years or more

What is your gender?

- Female
- Male
- I do not want to share this information.

What is your age?

- 18-24
- 25-34
- 34-45
- 45 years or older

SECTION 2: Scoring the barriers using the Likert scale

Below are 25 possible barriers obtained as a result of literature research. Detailed explanations of the relevant barriers are written below. In the adaptation of İndustry 4.0 technologies to the production sector, you should give a score of 5 for the barrier that you think is “too effective” and a score of “1” for the barrier that you think is “too little effective”. The corresponding points are as follows.

5: Too effective
4: It has effect
3: Partially effective
2: Less effective
1: No effect

Barrier: Workers’ resistance

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of digital culture

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of trained staff

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Employment disruption

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: High implementation cost

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Seamless integration and compatibility issues

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Poor R&D on industry 4.0 adoption

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Inadequate maintenance support system

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of methodical approach for implementation

	1	2	3	4	5

No effect	O	O	O	O	O	Too effective

Barrier: Problem of coordination and collaboration

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Time constraint

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of experience in project management and budgeting

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of risk management tools for investments

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of clear apprehension of benefits

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Fear of failure

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of government support and policies

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Compatibility Issues between existing and new systems

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of infrastructure and internet- based networks

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Data security and data protection

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of standards and reference architectures

	1	2	3	4	5	

No effect	O	O	O	O	O	Too effective

Barrier: Lack of management dedication, commitment, and leadership

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Lack of futuristic outlook

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Managing employee anxiety

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Undeveloped of social infrastructure

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

Barrier: Regulatory compliance concerning social requirements

	1	2	3	4	5	
No effect	O	O	O	O	O	Too effective

SECTION 3: Ranking of barriers from most effective to least effective

Can you rank the ones you think are the most effective out of the 25 barriers you have just given points, by placing the most important one in the 1st rank? While sorting, you need to give numbers between 1-25 for the items.

Barrier: Workers' resistance
Your answer: __

Barrier: Lack of digital culture
Your answer: __

Barrier: Lack of trained staff
Your answer: __

Barrier: Employment disruption
Your answer: __

Barrier: High implementation cost
Your answer: __

Barrier: Seamless integration and compatibility issues
Your answer: __

Barrier: Poor R&D on industry 4.0 adoption
Your answer: __

Barrier: Inadequate maintenance support system
Your answer: __

Barrier: Lack of methodical approach for implementation
Your answer: __

Barrier: Problem of coordination and collaboration
Your answer: __

Barrier: Time constraint
Your answer: __

Barrier: Lack of experience in project management and budgeting
Your answer: __

Barrier: Lack of risk management tools for investments
Your answer: __

Barrier: Lack of clear apprehension of benefits
Your answer: __

Barrier: Fear of failure
Your answer: __

Barrier: Lack of government support and policies
Your answer: __

Barrier: Compatibility Issues between existing and new systems
Your answer: __

Barrier: Lack of infrastructure and internet-based networks
Your answer: __

Barrier: Data security and data protection
Your answer: __

Barrier: Lack of standards and reference architectures
Your answer: __

Barrier: Lack of management dedication, commitment, and leadership
Your answer: __

Barrier: Lack of futuristic outlook
Your answer: __

Barrier: Managing employee anxiety
Your answer: __

Barrier: Undeveloped of social infrastructure
Your answer: __

Barrier: Regulatory compliance concerning social requirements
Your answer: __