A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey

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ABSTRACT

Recently, various researchers have proposed various Maturity Models (MMs) for assessing Industry 4.0 (I4.0) readiness and adoption, but few have proposed frameworks (F/Ws) for the implementation of I4.0 for smart manufacturing enterprises. This thesis focuses on the awareness, knowledge, readiness, adoption, willingness to invest, challenges, and benefits of I4.0 for Smart Manufacturing Enterprises in Turkey. The aims of this thesis are (1) to review the research related to existing I4.0 MMs and F/Ws, (2) to propose a modular MM with four dimensions, five levels, 60 second-level dimensions, and 246 sub-dimensions, and a generic F/W with four layers and seven hierarchy levels, (3) to conduct a case study by applying the proposed MM and F/W to assess and measure the I4.0 adoption of an automobile parts smart manufacturing enterprise, (4) to apply a Technology Forecasting (TF) model to expect the growth of I4.0 for the enterprise, (5) to perform a SWOT analysis to understand the weaknesses, strengths, opportunities, and threads for Turkey toward I4.0 transition, (6) to identify the I4.0 readiness/awareness, I4.0 advantages, challenges and willingness to invest by surveying 100 Turkish manufacturers, and (7) to have a detailed discussion on advantages and challenges foreseen in the transition to in the context of Turkey. Case study findings show that the enterprise's overall maturity score was found to be 2.73 out of 5.00 i.e. it is still in the early stage of the I4.0 integration, and if the enterprise takes actions to create a roadmap toward a smooth I4.0 transition the forecasted year of full integration of I4.0 is between 2031 and 2034. Survey findings show that enhanced product quality and expanding the business into new markets are the most highlighted advantages of I4.0 whereas, the openness of employees to new technology, insufficient funds, and economic factors are the most highlighted I4.0 challenges.

Keywords: Reference Framework, Industry 4.0, Smart Manufacturing, Technology Forecasting, Maturity Model, Operator 4.0, Factory 4.0, Management 4.0, Logistics 4.0

ÖZ

Güncel olarak, birçok araştırmacı, Endüstri 4.0 (I4.0)'ın adaptasyon sürecini değerlendirmek için çeşitli Olgunluk Modelleri (MM'ler) önermektedir, ancak bu çalışmalardan çok azı akıllı üretim işletmeleri için I4.0'ın uygulanabilmesine yönelik çerçeveler (F/W'ler) önermiştir. Bu doktora tezi, I4.0'ın benimsenmesinden fiili ve potansiyel faydaları / zorlukları belirlemeye ve Türkiye'de I4.0'ın benimsenmesinden maksimum potansiyeli elde etmek için Türk üreticilerin I4.0'ı benimseme yönünde harekete geçme konusundaki farkındalığını artırmaya katkıda bulunur. Bu tezin amacı: (1) literatür taraması yaparak mevcut olgunluk modellerinin, hazırlık çerçevelerinin incelenmesi, (2) dört boyut, beş seviye, 60 ikinci seviye boyut ve 246 alt boyuta sahip bir modüler olgunluk modeli önerilmesi ve dört katman ve yedi hiyerarşi seviyesi ile genel bir çerçeve önerilmesi, (3) otomobil parça üretimi yapan fabrikada I4.0 benimsenmesini değerlendirmek ve ölçmek için önerilen olgunluk modelinin ve hazırlık çerçevesinin uygulanabilmesi için bir anket yapmak, (4) fabrikadaki I4.0 gelişimini değerlendirmek için teknoloji tahmininde bulunmak, (5) Türkiye'nin I4.0 geçişine yönelik zayıf yönlerini, güçlü yönlerini, fırsatlarını ve tehditlerini anlamak için bir SWOT analizi yapmak, (6) I4.0 hazırlık, farkındalık, I4.0’a yatırım yapma istekliliğini değerlendirmek amacıyla farklı sektörlerden 100 kişiyi anket çalışmasına dahil etmek ve, ayrıca (7) Türkiye’de I4.0’a geçişte öngörülen avantajlar ve zorluklar hakkında ayrıntılı bir tartışma yapmaktır. Vaka çalışması bulguları, şirketin genel olgunluk puanının 5,00 üzerinden 2,73 olduğunu gösteriyor. Şirketin I4.0 olgunluğu, teknoloji tahmini ile birlikte değerlendirildi ve şirketin I4.0 entegrasyonunun henüz olguluğa erişmekte olan seviyesinde “Hücre Düzeyinde” olduğu değerlendirildi. Teknoloji tahmini bulgularına göre, işletme sorunsuz bir I4.0 geçişine doğru bir yol

haritası oluşturmak için harekete geçerse, I4.0'ın tam entegrasyonunun öngörülen yılı 2031 ile 2034 arasında olduğu önörüldü. Anket bulguları, artan ürün kalitesinin ve işi yeni pazarlara genişletmenin I4.0'ın en çok vurgulanan avantajları olduğunu gösterirken, çalışanların yeni teknolojiye açıklığı, yetersiz fonlar ve ekonomik faktörler en çok vurgulanan I4.0 zorluklarıdır.

Anahtar Kelimeler: Genel Çerçeve Modeli, Endüstri 4.0, Akıllı Üretim, Teknoloji Tahmini, Olgunluk Modeli, Operatör 4.0, Fabrika 4.0, Yönetim 4.0, Lojistik 4.0

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence.
AR	Augmented Reality.
BDA	Big Data Analytics.
CAD	Computer-Aided Design.
CPS	Cyber-Physical System.
CRM	Customer Relationship Management.
ERP	Enterprise Resource Planning.
HRC	Human-Robot Collaboration.
IaaS	Infrastructure as a Service.
IIoT	Industrial Internet of Things.
IoT	Internet of Things.
IT	Information Technology.
KPI	Key Performance Indicator.
MÜSİAD	Independent Industrialists and Businessmen Association of Turkey.
OEM	Original Equipment Manufacturer.
TEYDEB	Direction of Technology and Innovation Support Programs.
TİM	Turkish Exporters Assembly.
TOBB	Union of Chambers and Commodity Exchanges of Turkey.
TÜBITAK	Scientific and Technological Research Council of Turkey.
TÜSİAD	Turkish Industry and Business Association.

Chapter 1

INTRODUCTION

1.1 Introduction to Industry 4.0

The industry has progressed through three major revolutions, each contributing to momentous transformations in various facets of manufacturing and thus passing enormous benefits for humankind and societies. Kagermann, Lukas, and Wahlster (2011) states that the fourth Industrial revolution (I4.0) includes development in automation and intelligent observation and decision-making processes. Nevertheless, I4.0 was introduced in academia by the publication of "manifesto" in 2013 by the German National Academy of Sciences and Engineering. The industry has progressed through three major revolutions, each momentous contributing transformation in various facets of manufacturing and providing enormous benefits for humankind and societies. Four different industrial revolutions can be found in the literature, as presented in Figure 1.1.

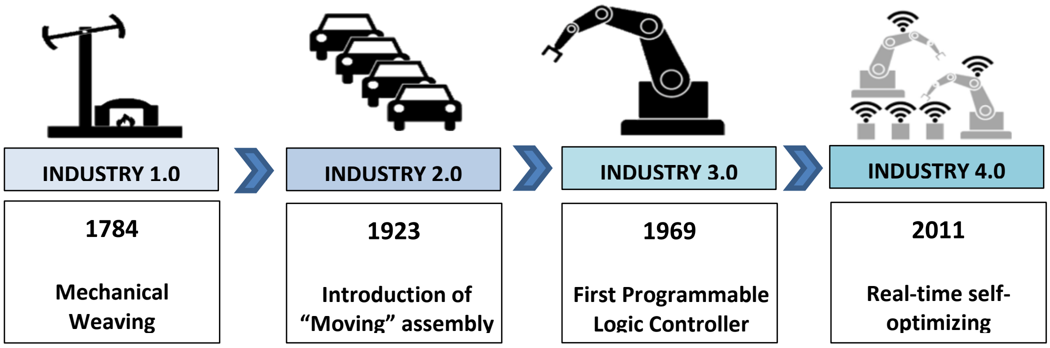


Figure 1.1: Industrial revolutions. Adapted from (Akay, 2018; UNIDO, 2017)

The term “Industrie 4.0” comes from a project in the high-tech strategy of the German government, stimulating the digitalization of manufacturing, intending to support small and medium-sized enterprises (SMEs), help them to exploit I4.0 strategies in terms of standardization and norms, security, legal F/Ws, research, and workforce transformation (Stiftung, 2017). The term Industry 4.0 (I4.0) comes from a project in the high-tech strategy of the German government aimed at stimulating the digitalization of manufacturing and supporting small and medium-sized enterprises (SMEs), helping them to exploit I4.0 strategies in terms of standardization and norms, security, legal F/Ws, research, and workforce transformation (Stiftung, 2017). I4.0 abbreviation is the most common term referring to I4.0 in academic research (Dastbaz, 2019; Jovanovski, Seykova, Boshnyaku, & Fischer, 2019; Ramirez-Peña, Sotano, Pérez-Fernandez, Abad, & Batista, 2020; D. O. M. Sanchez, 2019). The concept of I4.0 is envisioned as the significance of the interconnectivity between the departments of an organization. I4.0 is more about intelligent manufacturing systems such as self-adapting processes and real-time communication beyond traditional automation (Alcácer & Cruz-Machado, 2019). I4.0 vision manages the value chain across the product life-cycle. It also involves ordering, development, production, and providing customized product demands (Cinar, Zeeshan, Solyali, & Korhan, 2020). Real-time monitoring availability through the connection of all objects in the value chain allows precise predictions about the capacity to determine the optimal value flow. Based on the predictions, operations can be optimized according to cost, availability, and resource consumption (Weston & Cui, 2008).

1.2 Key Technologies of Industry 4.0

I4.0 depends on a variety of novel technological developments. The Boston Conculting Group (BCG) (2016) identifies the following Nine Technologies transforming industrial Production as shown in Figure 1.2.

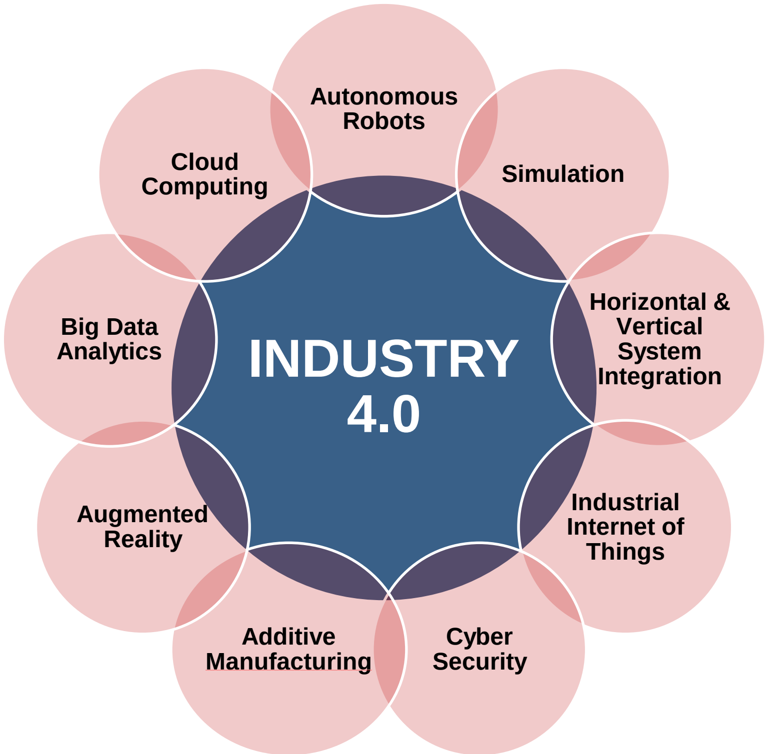


Figure 1.2: Nine Technologies of I4.0. Adopted from (UNIDO, 2017).

To further understand the technological requirements for manufacturing enterprises to become (I4.0) recognized, the nine I4.0 pillars (Erboz, 2017); 1) autonomous robots, 2) simulation, 3) horizontal and vertical system integration, 4) industrial internet of things (IIoT), 5) cybersecurity, 6) additive manufacturing, 7) augmented reality, 8) big data analytics and, 9) cloud computing is used to demonstrate how SMEs should incorporate emerging technologies to become automated, autonomous, and optimized (Cinar, Nuhu, Zeeshan, & Korhan, 2020; Saad, Bahadori, & Jafarnejad, 2021). Subsequently, increasing complexity on all enterprise levels creates uncertainty about respective organizational and technological capabilities and adequate strategies to develop them (Schumacher, Erol, & Sihn, 2016). Companies are overwhelmed and seem incapable of designing effective execution plans given recent changes in the technological transition to smart factories and the I4.0 revolution (Hübner et al., 2017). I4.0 advances where the internet and nine I4.0 pillars serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines, and processes across organizational boundaries to form (Schumacher et al., 2016). Each enterprise should determine the conditions and individual specifications, then pick the I4.0 principles that provide the greatest chances of fulfilling the objectives (Matt, Rauch, & Riedl, 2018). Therefore, there is a need to create effective models and instruments to determine the existing state or maturity of technological advances in manufacturing organizations and apply I4.0 principles depending on their suitability for a specific enterprise (Rauch et al., 2020).

1.3 Aims of the Study

In this thesis, we investigate I4.0 adoption by exploring; The aims of this thesis are (1) to review the research related to existing I4.0 MMs and F/Ws; (2) to propose a modular MM with four dimensions, five levels, 60 second-level dimensions, and 246 sub-dimensions, and a generic F/W with four layers and seven hierarchy levels; (3) to conduct a case study by applying the proposed MM and F/W to assess and measure the I4.0 adoption of an automobile parts smart manufacturing enterprise; (4) to apply a Technology Forecasting (TF) model to expect the growth of I4.0 for the enterprise, (5) to perform a SWOT analysis to understand the weaknesses, strengths, opportunities, and threads for Turkey toward I4.0 transition, (6) to identify the I4.0 readiness/awareness, I4.0 advantages, challenges and willingness to invest by surveying 100 Turkish manufacturers, and (7) to have a detailed discussion on advantages and challenges foreseen in the transition to in the context of Turkey. Therefore, a new MM was developed based on a reference F/W utilized to evaluate the adoption of the I4.0 technologies. The research also focuses on the awareness, knowledge, readiness, willingness to invest, challenges, and benefits toward the I4.0 transition. A questionnaire designed for primary data acquisition. Finally, based on availability and acquired data, the proposed MM is applied to assess I4.0 readiness and adoption. Then TF is applied to predict the I4.0 adoption roadmap of the manufacturers.

1.4 Research Significance and Motivation

Most of the work described in this thesis was conducted at Eastern Mediterranean University (EMU) in Northern Cyprus, TRNC. The reasons for conducting the research work at this university were: (1) I have served as a process development engineer in the mechanical engineering department of BorgWarner in Izmir, Turkey for 4 years, and have a good understanding of assessment practices in the industry; (2) I have been actively involved in the development of new production lines that produce automotive part productions and have a good understanding of technology requirement in production centers; (3) Turkey's location at a very important geographic position called a global hub. To increase the competitiveness of Turkey, I4.0 integration to Turkish manufacturers is required. Contributions of this research were: (1) Explore the adoption of I4.0 based on the literature; (2) Identify the actual or possible benefits from integrating I4.0 technologies; (3) Recognize the challenges, limitations, and concerns for adopting I4.0 technologies; (4) Develop a new MM to evaluate I4.0 maturity of an enterprise; (5) Develop a survey to collect data from the real-world company; (6) Predict the growth in I4.0 knowledge, awareness, and adoption; (6) Provide insight into the current situation by exploring solutions for I4.0 integration and obtain the maximum potential of I4.0. Finally, this thesis enables to obtain a modular MM to assess the I4.0 adoption of a manufacturing enterprise to understand the current status of technology integration and guide them to take actions towards complete I4.0 adoption. The study is also performed to identify benefits and challenges from adopting I4.0 by exploring I4.0 knowledge, awareness to provide solutions to take the first step of I4.0 adoption. Therefore, this academic research fills the gap and influences industrial companies to move forward.

1.5 Research Objectives

The following objectives pursued in this research:

1) To conduct a systematic analysis of the literature related to this thesis, more specifically:
    a. I4.0 and its technologies,
    b. Practical application policies for I4.0,
    c. Smart factories and smart technologies involved in the transformation to I4.0.
    d. Existing MMs to assess the I4.0 maturity of manufacturing enterprises.
    e. Existing F/W models assess the I4.0 readiness of manufacturing enterprises.
    f. Recent developments, government policy initiatives, and business models on I4.0 in Turkey.
2) To analyze the gathered information from Objective I, more specifically:
    a. To identify groupings of commonalities between existing MMs, and
    b. Establish a link between the groupings and the literature in Objective I.
3) To propose a modular and generic MM/ F/W to:

   a. Analyze the level of knowledge, awareness, and readiness of I4.0 for smart manufacturing enterprises.
   b. Estimate the willingness of the Stakeholders/Manufacturers/Managers to invest in I4.0.
   c. Identify the economic, technological, and organizational difficulties and limitations for the Stakeholders/Manufacturers/Managers who consider adopting I4.0 technologies.
4) Develop an online survey questionnaire to:
   a. Assess I4.0 adoption and maturity of the Turkish manufacturer using proposed MM as a case study,
   b. Evaluate the readiness, awareness, and willingness to invest in I4.0 of Turkish manufacturers.
5) Report the survey findings to analyze the maturity of manufacturers by interpreting and presenting relational maps of the data acquired through MM and visually representing it through spider web diagrams to create a visual representation of the results.
6) Identify and discuss the challenges in Smart Manufacturing for transition to I4.0 and propose a way forward for further research.
7) Apply an appropriate TF model to anticipate I4.0 growth.
8) Propose a F/W for smart manufacturing firms toward the I4.0 transition.
9) To recommend follow-up work related to the research in this thesis which may pursue in the future.

1.6 Thesis Organization

The academic work is subdivided into six parts: introduction, literature review, research methodology, development of a new MM and F/W integrated with TF, I4.0 readiness, advantages and challenges of smart manufacturing enterprises in Turkey, and conclusion.

The introductory chapter consists of six parts, which provide a basic overview of the Ph.D. thesis substance. The introduction describes the current situation concisely, characterized by numerous I4.0 key technologies and their importance toward the 4th industrial revolution. Afterward, the aim of the study, research objectives, and research significance followed. Finally, the structure of the thesis is presented. The second chapter of the thesis can be considered the theoretical backbone of academia and aims to provide a thorough overview of the literature and the definition of I4.0 and associated terms. The fundamentals of the I4.0 and the importance of I4.0 for Turkey are highlighted in this section. The core part of the entire thesis is represented in the third, fourth, and fifth chapters. Chapter three provides the research strategy, philosophy, the approach of the thesis. Chapter four presents the development of a MM and F/W integrated with TF. The systematic literature review is conducted with the research method and approach, in which a solid theoretical fundament is determined. Finally, this chapter provides a roadmap for smart manufacturing enterprises. Chapter five considers the I4.0 readiness, advantages, and challenges of Turkish manufacturing companies. A survey is conducted, and survey results are presented in this chapter. The thesis is concluded with the conclusion in chapter eight by summarizing the work accomplished and further research suggestions.

Chapter 2

LITERATURE REVIEW

2.1 Industry 4.0 Program

Qin, Liu, and Grosvenor (2016) recognize the following as constituents of I4.0 services. The foundation is the real-time information availability by integrating smart objects in the business. Self-optimized systems, self-adapting processes, and value-adding networks are provided by the environment, where human and smart sensors are interconnected to optimize cost, availability, and resource consumption.

The I4.0 program considers the following components (Qin et al., 2016):

1) **Smart factory**, A smart factory is an intelligent, interconnected factory. Completing I4.0 integration in traditional production allows for distributed and fully automated operations, auto-guided systems through production, and real-time monitoring of product operations.
2) **Smart management** provides real-time data exchange between stakeholders, leading to integrating communication systems between suppliers, customers, manufacturers and minimization of carbon footprint, pollution, emissions, and raw materials.
3) **Smart products** include data transmitting and information through integrated sensors and processors.

4) **Smart Logistics**, requiring products with any function and modify their order at any time of the production process. Additionally, smart products guiding and supporting customers during their use.

2.2 Design Principles of I4.0

Reviewing the literature is the preliminary step towards the effective development of I4.0 assessment tools. Literature reviews associated with the methodological structure in which generic F/W is proposed base on reviewed articles.

The systematic literature review pursues the objective of providing a general description of I4.0, which enjoys the approbation of the academic and industrial environment. To provide a general explanation for I4.0, the number of four design principles; 1) interconnection, 2) information transparency, 3) decentralized decisions, and 4) technical assistance, presented in Figure 2.1 (Hermann, Pentek, & Otto, 2016).

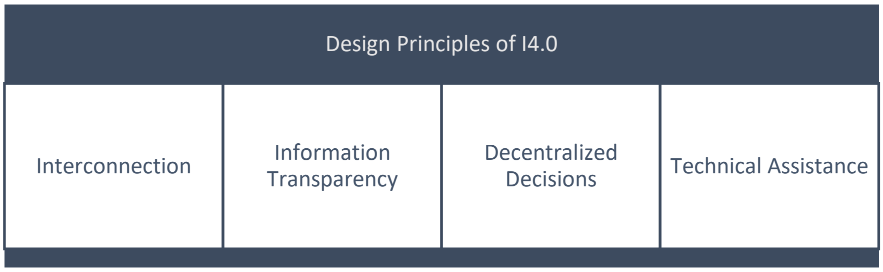


Figure 2.1: Design Principles of I4.0 (Hermann et al., 2016).

2.2.1 Interconnection/ Interoperability

I4.0 is inextricably linked to umbrella-term connectivity. Connectivity is a self-explanatory concept that includes interoperability and integration. The efficient implementation of connectivity is a delicate task and scrutinizes the theme of interoperability.

Interoperability is defined as a measure of how individuals, organizations, and diverse systems work together to succeed in a common goal Ide and Pustejovsky (2010). Linking interoperability with I4.0 can provide unique software procedures, approaches, and solutions to the industrial environment (Razzaque, Milojevic-Jevric, Palade, & Clarke, 2015). Architecture is established to certify a diagnostic analysis of subsequent concerns, and it has four levels; technical, operational, semantic interoperability, and systematical (Berre et al., 2007).

The operational or organizational interoperability emphasizes the language structure, norms, and interdependence between CPS and I4.0. The relevant interoperability is concerned with deciding directives, techniques, structures, and specifications. Finally, the architecture's final level can be depicted. Semantic interoperability serves as a guarantee for data or knowledge sharing between humans and computers. The explanation of the architecture model is a necessary precondition for the implementation of the F/W. Interconnected environment, autonomy, and coexistence are associated with interoperability (D. Chen, Doumeingts, & Vernadat, 2008), whereas connectivity is equated with uniformization, coordination, and coherence (D. Chen et al., 2008). Enterprise integration is defined as a method to ensure business entities accomplish business objectives (ISO).

Hermann et al. (2016) stated that machines, devices, sensors, and people are connected over the Internet of Things (IoT) and Internet of People (IoP) and form the Internet of Everything (IoE). Wireless communication technologies play a prominent role in the increasing interaction as they allow for ubiquitous internet access. Via the IoE, interconnected objects and people can share information, which forms collaboration for reaching common goals (Giusto, Iera, Morabito, & Atzori, 2010). There are three types of collaboration within the IoE: human-human collaboration, human-machine collaboration, and machine-machine collaboration (G Schuh, Potente, Wesch-Potente, & Hauptvogel, 2013). For connecting machines, devices, sensors, and people with each other, common communication standards are of great importance. Such standards enable the flexible combination of modular machines from different vendors (Zuehlke, 2010). Integration of modularization allows smart factories to adapt to market changes and customized product demands. However, cybersecurity is required to prevent harmful offenses because of the increase in usage of IoT (Lu, Li, Qu, & Hui, 2014).

Related questions in the questionnaire are shown below:

1. What proportion of the process and system infrastructure can be controlled through automation?
2. To what extent are machines and operational systems integrated (M2M)?
3. To what extent are cloud solutions used in data processing?
4. To what extent is the current supply chain integrated?
5. To what extent do departments collaborate?

2.2.2 Information Transparency

Information transparency enabled by the increasing number of connected objects and people (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014), the fusion of the physical and virtual world enables a new form of information transparency (Kagermann, 2015). Through linking sensor data with digitalized plant models, a virtual copy of the physical world is created.

For IoE participants to make appropriate decisions, context-aware knowledge is required. Context-aware systems use data from both the virtual and physical worlds to complete their tasks. Electronic records, sketches, and simulation models are just a few examples of virtual world knowledge (Lucke, Constantinescu, & Westkämper, 2008). Raw sensor data must be aggregated to the higher-value context information and interpreted to analyze the physical world. The data analytics results need to be embedded in assistance systems that are transparent and accessible to all IoE participants (Gorecky, Schmitt, Loskyll, & Zühlke, 2014).

Related questions in the questionnaire are shown below:

1. How are operations data collected, and in which areas?
2. How much of the operations data collected is used, and for what purposes?
3. To what extent can products be tracked throughout their life-cycle?
4. To what extent does the supply chain have end-to-end visibility?

2.2.3 Decentralized Decisions

Decentralized decision-making is based on the interconnection of objects and people and the transparency of information from a manufacturing facility. Interconnected and decentralized decision-makers allow using local information with global information simultaneously to provide enhanced decision-making and increased productivity (Hermann et al., 2016). Systems supporting IoE perform assigned tasks autonomously without delegation. However, in case of interferences, exceptions, or conflicting goals, assigned tasks are delegated to higher levels (Otto, 2014). CPS enables decentralized decisions as the technologies of CPS provide controlling the physical world without human assistance (E. A. Lee, 2008).

Related questions in the questionnaire are shown below:

1. To what extent does the leadership team support I4.0?
2. To what extent do departments collaborate?
3. To what extent are employees equipped with relevant skills for I4.0?

4. How much of the operations data collected is used, and for what purposes?

2.2.4 Technical Assistance

In smart companies, the role of the human is shifted from the point of operator view to a more intelligent view that includes making strategic decisions and solving problems in production. Integration of CPS and IoT technologies increases the complexity of the systems as complex networks; decentralized decisions are used in these technologies, humans are required to have assistance systems due to the complexity of the systems. These systems need to aggregate and visualize information comprehensibly to ensure that humans can make informed decisions and solve urgent problems on short notice (Gorecky et al., 2014).

Currently, smartphones and tablets play a central role in connecting people with the IoT (Miranda et al., 2015). Wearables are predicted to become increasingly important in the future as soon as current challenges such as their energy supply are overcome (Williamson et al., 2015).

With further advances in robotics, the physical support of humans by robots is regarded as another aspect of technical assistance as robots can conduct a range of tasks that are unpleasant, too exhausting, or unsafe for their human co-workers (Awais & Henrich, 2013; Kiesler & Hinds, 2004). For an effective, successful, and safe support of humans in physical tasks, it is necessary that robots interact smoothly and intuitively with their human counterparts (Awais & Henrich, 2013) and that humans are properly trained for this kind of human-machine collaboration (Jaschke, 2014).

Related questions in the questionnaire are shown below:

1. To what extent are machines and operational systems integrated (M2M)?

2. To what extent are cloud solutions used in data processing?
3. How much of the operations data collected is used, and for what purposes?
4. To what extent are employees equipped with relevant skills for I4.0?
5. To what extent does the leadership team support I4.0?

2.3 Industry 4.0: Maturity Models

Large enterprises in developed countries have already completed their transition to I4.0 or are in the transformation stage. Many researchers have highlighted the importance of I4.0 technologies in manufacturing systems (Chonsawat & Sopadang, 2021; Coatney & Poliak, 2020; Davidson, 2020; Duft & Durana, 2020; Horick, 2020; Hyers, 2020; Peters, Kliestik, Musa, & Durana, 2020; Saad et al., 2021; Sartal, Bellas, Mejías, & García-Collado, 2020). Surveys and analyzes are required to understand the I4.0 awareness and readiness of a country. Therefore, the MM methodology can be used to observe a country's readiness or organization's readiness. In general, maturity is described as being complete, ideal, or ready (Simpson & Weiner). The capabilities of technological and organizational studies can be increased over time by maturing the systems. MMs (MMs) are commonly used to indicate the maturity of a process or an organization. Maturity may be measured discretely or continuously, qualitatively or quantitatively (Kohlegger, Maier, & Thalmann, 2009). Readiness and maturity can be distinguished from each other: readiness assessment is required before engaging in the maturing process, whereas maturity assessment aims to capture the current state during the maturing process.

Gökalp, Şener, and Eren (2017) analyzed seven MMs according to scope, objective, completeness, and clarity. Existing MMs in terms of origin, institution, approach, and structure have been analyzed in this study. To assess Turkey's readiness, Akdil, Ustundag, and Cevikcan (2018) introduced a novel MM focused on three dimensions: services, strategy and organization, and smart business processes and smart products, and four levels: level 0 = absence, level 1 = life, level 2 = survival, and level 3 = maturity. They have also surveyed companies to understand their current state of technology for I4.0, in which human resources, smart marketing, and smart finance were recognized as key contributors to increasing companies' perspectives on I4.0. The operator role in the context of I4.0 was defined by (Fallaha, Cinar, Korhan, & Zeeshan, 2020). Temur, Bolat, and Gözlü (2018) reviewed I4.0 readiness level evaluation methodologies and applied the IMPULS MM to three different Turkish manufacturers regarding operational and socioeconomic perspectives from various industrial sectors. They concluded that manufacturers have failed to create road maps and new workforce planning strategies in the I4.0 revolution.

Bauer and Horváth (2015) stated that I4.0 technologies significantly influence Germany's gross domestic product (GDP), providing an expected increase of 23% (EUR 78.77 billion) in the years between 2013 and 2025. In this context, smart manufacturing enterprises should try to reshape their operations in line with the I4.0 technologies to prevent losing competitiveness. I4.0 technologies are in their early phases of growth. Therefore, it is critical to define a strong structure and a clear methodology as application guidelines toward the I4.0 revolution (Gökalp et al., 2017). Providing comprehensive guidance and introducing a road map are organizational approaches such as F/Ws or MMs. The MM is a tool that provides an assessment of the current effectiveness of the system. In other words, MMs are used to define the level of a system's effectiveness within the context of I4.0 technologies. Accordingly, as the degree of the system's maturity increases, better progress occurs in various characteristics that contribute to the enterprise's maturation. MM levels and dimensions are used to define the degree of a system's maturity.

Existing MMs in terms of origin, institution, approach, and structure have been analyzed in Table 2.1. All MMs under study have some common features and a common goal, yet they have some uniqueness in their approaches according to the definition and number of levels and dimensions. An exclusive MM for assessing the adoption of I4.0 is urgently needed because of its unique social and cultural challenges and constraints.

Table 2.1: Existing MMs, adapted from (Schumacher et al., 2016).

MM	Origin	Institution/Source	Assessment Approach	Levels/Dimensions/Items
The Connected Enterprise Maturity Model (Rockwell Automation, 2014)	USA	Rockwell Automation	A five-stage approach to identifying I4.0; technology assessment has 4 dimensions and 5 levels	5 levels and 4 dimensions, no details about items
IMPULS[1] – Industry 4.0 Readiness (IMPULS, 2015)	DE	Manufacturing enterprises	IMPULS MM is developed by a German aircraft manufacturer that specialized in beginner and flight training hang gliders	6 levels, 6 dimensions, 18 items
RAMI4.0 (Hankel & Rexroth, 2015)	DE	Society for measurement, automation, and technology	The Reference Architecture Model Industry (RAMI 4.0) MM has a three-dimensional structure that shows how to approach I4.0	6 levels, 7 dimensions, no details about items
Digital Maturity and Transformation (Back, Berghaus, & Kaltenrieder, 2015)	CH	Manufacturing enterprises	It contains nine dimensions: Product innovation, Information Technology (IT), process digitalization, culture and expertise, customer experience, product innovation, strategy, organization, collaboration, transformation management	9 dimensions, no details about levels and items
I4.0 Reifegradmodell (Jodlbauer & Schagerl, 2016)	DE	FH - Oberösterreich	Assessment of maturity; no details for items and development of this MM is not finished yet	10 levels, 3 dimensions, 13 items

[1] IMPULS: German aircraft manufacturer.

Empowerment and Implementation Strategies for I4.0 (Lanza, Nyhuis, Ansari, Kuprat, & Liebrecht, 2016)	DE	The method is illustrated on a stator assembly for an electrical drive with 30 single teeth and a housing	Assessment of I4.0 MM is used to check and realize a part of a process model quickly	No details about levels, dimensions, or items
MM for Industrial Internet (Menon, Kärkkäinen, & Lasrado, 2016)	FI	Heavy-equipment manufacturing industries	Provides systematic design guidelines for industrial internet MM for mass production manufacturing industries	No details about levels, dimensions, or items
A Categorical F/W of Manufacturing for I4.0 (Qin et al., 2016)	UK	Manufacturing enterprises	The five levels contain four dimensions: factory, business, products, and customers	5 levels, 4 dimensions, no details about items
I4.0 / Digital Operation Self-Assessment (PricewaterhouseCoopers (PWC), 2016)	DE	PricewaterhouseCoopers	Online self-assessment with seven dimensions split into three stages of digital maturity; three of the six maturity dimensions require the use of a consultancy instrument for evaluation	3 levels, 6 dimensions, no details about items
SIMMI 4.0 (Leyh, Bley, Schäffer, & Forstenhäusler, 2016)	DE	-	Systems Integration MM I4.0 (SIMMI 4.0) has five maturity stages presented in five levels and four dimensions to evaluate the level of maturity; no exploratory case study has been conducted	5 levels, 4 dimensions, no details about items
A MM for Assessing I4.0 Readiness (Schumacher et al., 2016)	DE	Manufacturing enterprises	Readiness and MM specifically used to evaluate the readiness and maturity of manufacturing enterprises	5 levels, 9 dimensions, 62 items
ACATECH I4.0 Maturity Index (Günther Schuh, Anderl, Gausemeier, Ten Hompel, & Wahlster, 2017)	DE	ACATECH, National Academy of Science and Engineering	Value-based development stages presented in the model	6 dimensions, no details about levels or items
SPICE-based I4.0 MM (Gökalp et al., 2017)	TR	No exploratory case study	Software Process Improvement Capability Determination (SPICE)-based I4.0 MM evaluates system maturity in light of I4.0	6 levels, 9 dimensions, no details about items
DREAMY (De Carolis, Macchi, Negri, & Terzi, 2017)	I	Manufacturing enterprises	Digital Readiness Assessment MM (DREAMY) used to help manufacturing enterprises to create a roadmap for I4.0 integration	5 levels, 6 dimensions, no details about items
The University of Warwick (WMG) MM (The University of Warwick (WMG), 2017	UK	Crimson & Co., Pinsent Masons	Online self-assessment provided for this model to evaluate the maturity of a company	4 levels, 6 dimensions, 53 items
Maturity and Readiness Model for I4.0 (Akdil et al., 2018)	TR	A retail company operating in Turkey	Measures companies' maturity and business levels	4 levels, 3 dimensions, 13 items

Existing MMs in the literature are reviewed to determine the sufficiency of the models in terms of evaluation of the organization's maturity for the adoption of I4.0 technologies and identification of MM's strengths and weaknesses. There are 16 different MMs found in the literature, and each of them was reviewed.

Connected Enterprise MM (Rockwell Automation, 2014): Connected Enterprise MM was assessed on five maturity levels; however, the MM dimensions of the model were not mentioned, so no information is available regarding MM dimensions or MM items.

IMPULS (IMPULS, 2015): The maturity stage of competitor companies influences the maturity level. In other words, the maturity stage of the market is evaluated if other businesses in the same market were involved in the survey; otherwise, they are disregarded.

RAMI 4.0 (Hankel & Rexroth, 2015): The RAMI model has six levels: business, functional, information, communication, integration, and assets; and has seven dimensions: product, field device, control device, station, work centers, enterprise, and connected world. This model is used to evaluate the system's maturity and take action to complete the I4.0 integration. However, there is no information provided regarding items, and the structure does not include the operator role in the I4.0 technologies.

Digital Maturity and Transformation MM (Back et al., 2015): The assessment contains nine dimensions, but there is no information about levels and items. The structure of the model is not presented in their research.

I4.0 Reifegradmodell MM (Jodlbauer & Schagerl, 2016): There are three dimensions, and ten levels indicated this in the assessment of maturity. There are no details provided for the items or development of this MM, and it is not yet finished.

Empowerment and Implementation Strategies for I4.0 MM (Lanza et al., 2016): The maturity evaluation of a company is a limited portion of the analysis of the I4.0 revolution. No full explanations are available in terms of the MM's composition or its dimensions and items.

A Categorical F/W of Manufacturing for I4.0 (Qin et al., 2016): This is a F/W proposed to identify the need for the fourth industrial revolution, including five levels: connection, conversion, cyber, cognition, and configuration. Dimensions are defined as factory, business, products, and customers. However, there are no details about the items or dimensions.

I4.0/Digital Operations Self-Assessment (PricewaterhouseCoopers (PWC), 2016): This is an online self-assessment tool-based MM for I4.0 readiness, with attention specifically paid to digital readiness for I4.0. The model has six dimensions. Dimensions and items are neither presented in their study nor shared with the users.

SIMMI 4.0 (Leyh et al., 2016): Software and technological aspects of maturity are considered evaluating the maturity of the business. The organizational (such as company vision and employees) and environmental (such as market structure and competitors) aspects are not considered in the MM.

A MM for Assessing I4.0 Readiness and MM (Schumacher et al., 2016): This MM proposes nine dimensions for the assessment; the dimensions are leadership, culture, technology, strategy, customer, products, people, operations, and governance. The assessment method is based on the Likert-scale rating methodology. The advantage of this model is that it is easy to use for maturity level assessment but only proposes an average ranking without any additional details.

ACATECH I4.0 Maturity Index (Günther Schuh et al., 2017): Value-based development stages are presented in this model and the dimensions are identified as computerization, connectivity, visibility, transparency, predictive capacity, and adaptability. However, there are no details about items or levels.

SPICE-based MM (Gökalp et al., 2017): SPICE-based I4.0 MM was proposed to evaluate a system's maturity in terms of I4.0. This model has six levels: incomplete, performed, managed, established, predictable, and optimizing and has nine dimensions: process performance, performance management, work-product management, process deployment, process definition, process control, process measurement, process innovation, and continuous optimization. No details are available for the items, and the scope of the dimensions does not include data protection or culture impacts for I4.0 integration.

A MM for Assessing the Digital Readiness (De Carolis et al., 2017): The DREAMY model is used to help manufacturing enterprises to create a road map for I4.0 integration. MM has five levels: initial, managed, defined, integrated and interoperable, and digital-oriented; and five dimensions: process, monitoring, control, technology, and organization. The items are defined in their model. However, the operator role in I4.0 is not included in this model. No related items were found in the structure of the model. It does not provide an action plan to overcome weaknesses in full I4.0 integration.

WMG MM (The University of Warwick (WMG), 2017): The WMG model provides a practical method to assess companies' readiness and adoption for the cyber-physical age. Dimensions of the model are defined as supply chain, products and services, manufacturing and operations, business model, strategy and organization, and legal considerations. The levels are beginner, intermediate, experienced, and expert. In this study, 53 responses from 22 different countries were evaluated (The University of Warwick (WMG), 2017).

Maturity and Readiness Model for I4.0 (Lin et al., 2017): Mettler's architecture was used to construct this MM (Mettler, 2009). In the context of the industrial internet, the analysis establishes a concept guideline for MM. This model cannot be evaluated as a complete assessment since the research is not yet completed.

Our literature review summarizes an increase in the number of publications related to I4.0 in the past couple of years. Sixteen MMs were analyzed, and we concluded that none of them fully cover all the criteria of scope, fitness for purpose, completeness, clarity, and objectivity. Thus, no previous study has considered all the criteria available, so this research is unique as we considered all the criteria. The MMs are presented in Table 2.2 based on specific criteria. N-A, P-A, L-A, and F-A represent not achieved, partially achieved, largely achieved, and fully achieved, respectively.

Table 2.2: Summary of MMs. Adapted from (Gökalp et al., 2017).

MMs	Reference	Fitness of Purpose	Completeness	Dimension Granularity	Measurement Attribute	Complete Method	Objectivity
The Connected Enterprise	(Rockwell Automation, 2014)	N-A	P-A	N-A	N-A	N-A	N-A
IMPULSE	(IMPULS, 2015)	P-A	P-A	P-A	L-A	F-A	L-A
RAMI 4.0	(Hankel & Rexroth, 2015)	L-A	P-A	L-A	N-A	F-A	L-A
Digital Maturity	(Back et al., 2015)	P-A	L-A	P-A	P-A	P-A	P-A
I4.0 Reifegradmodell	(Jodlbauer & Schagerl, 2016)	P-A	P-A	P-A	L-A	F-A	L-A
I4.0 Empowerment and Implementation Strategies	(Lanza et al., 2016)	N-A	N-A	N-A	N-A	N-A	N-A
MM for Industrial Network	(Menon et al., 2016)	N-A	N-A	N-A	N-A	N-A	N-A
A categorical F/W of Manufacturing for I4.0	(Qin et al., 2016)	N-A	N-A	N-A	N-A	N-A	N-A
I4.0 / Digital operations Self-Assessment	(PricewaterhouseCoopers (PWC), 2016)	P-A	P-A	P-A	P-A	N-A	P-A
SIMMI 4.0	(Leyh et al., 2016)	P-A	P-A	P-A	P-A	L-A	P-A
A MM for Assessing I4.0 Readiness and Maturity	(Schumacher et al., 2016)	P-A	P-A	P-A	P-A	P-A	P-A
ACATECH I4.0 Maturity Index	(Günther Schuh et al., 2017)	P-A	P-A	N-A	N-A	N-A	P-A
SPICE-based MM	(Gökalp et al., 2017)	P-A	L-A	L-A	P-A	F-A	L-A
DREAMY MM	(De Carolis et al., 2017)	P-A	P-A	P-A	P-A	N-A	P-A
WMG MM	(The University of Warwick (WMG), 2017)	P-A	P-A	L-A	P-A	F-A	L-A
Maturity and readiness model for I4.0	(Akdil et al., 2018)	P-A	N-A	N-A	N-A	N-A	N-A

2.4 Industry 4.0: Standards and Framework

I4.0 fundamentally refers to integrating virtual environments with real operations, so engineering, logistics, and IT must work together smoothly (DIN Deutsches Institut für Normung, 2019). However, an efficient, effective, and rapid transformation and adaption of I4.0 is impossible without the standardization of products and processes across the globe (Rojko, 2017). There is a need to develop a common model of reference whose implementation would allow interaction among all interested parties and interconnection of the most diverse technology in use. Development of F/W can be accomplished by using a structured architecture that frames and integrates the principles, axioms, interactions, and specifications as a direction of mutual contact between all entities (M. A. d. S. Correia, 2014). In terms of a reference architecture, an F/W describes how a collection of structures and relationships allows a set of predetermined specifications to be met, and can provide recommendations in the form of best practices (M. A. d. S. Correia, 2014). Existing F/W models in terms of architecture, I4.0 technology, layers, levels, and life cycle value stream have been analyzed in this study.

The RAMI 4.0 model originated in Germany and meets the DIN SPEC 91345 standard, developed as an initial compilation of the vital technological elements of I4.0. It is seen as a requirement for implementing the I4.0 definition and a paradigm that needs global acceptance (Rojko, 2017). The RAMI 4.0 model was developed by BITCOM (Germany's Digital Association), VDMA (Germany's Engineering Industry Association), and ZWEI (Germany's Electrical Industry). It is based on the globally established Smart Grid Architecture Model (SGAM) launched in 2014, but with two additional bottom layers to address unique I4.0 aspects (Adolphs & Epple, 2015).

SGAM was originally envisaged and established for coordination in green energy source networks. The RAMI 4.0 model is a slight upgrade of the SGAM. (Zezulka, Marcon, Vesely, & Sajdl, 2016). The three-dimensional RAMI 4.0 MM aims to identify existing standards, to identify gaps, and to eliminate loopholes in the existing standards. The three-dimensional RAMI4.0 model is presented in Figure 2.2.

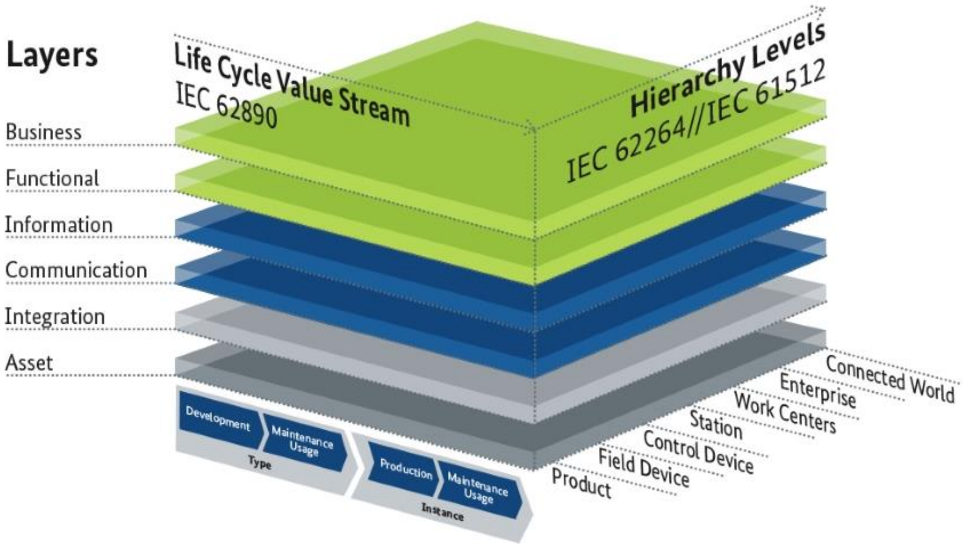


Figure 2.2: Reference Architecture Model for I4.0 (Adolphs & Epple, 2015).

New standards are being created by standardization organizations. Based on standards, architecture models are created to provide guidelines and standards for institutions toward the I4.0 revolution. Key standards for I4.0 are demonstrated in Table 2.3. The CEN-CENELEC-ETSI Smart Grid Coordination Group (2012) established an architecture model used for network communication in the scope of I4.0 applications.

Table 2.3: Key Standards for I4.0 (Enterprise Information Systems, 2017).

Application Area	Standard	Remarks
Engineering	IEC 62714	Automation Markup Language
	IEC 61987	Industrial-process measurement and control
	IEC 6130/ISO 13584	Industrial automation systems and integration
Life-cycle status	IEC 62890	Life-cycle status
Hierarchy Levels	IEC 62264	Enterprise-control system integration
	IEC 61512	Batch control

Information Layer	ISO 13584-42/IEC 61360	Classification and product description
Communication layer	IEC 62541	Machine to machine communication
	IEC 61784	Industrial communication networks
Digital Factory	IEC/TR 62794	A reference model for the digital factory
Configuration	IEC 61804	Function blocks for process control / electronic device description language
	IEC 62453	Field device tool (FDT) interface specification
Energy	IEC/ISO 20140	Energy Efficiency
Security	IEC 62443	Network and System Security
	ISO/IEC 27000	Information security management systems
Safety	IEC 61511	Functional safety
	IEC 62061	Safety of machinery
	ISO 13849	
Semantics	SPARQL	W3C Semantic Web stack
	RIF/SRWL	
	RDF(S)	
	OWL	
Condition	VDMA 24582	Condition monitoring

(Boğaziçi University, 2018) reported the importance of standardization for I4.0 and also highlighted that I4.0 standards play an essential role to increase Turkey's global competitiveness. It is announced that the technology standardization strategy for I4.0 should be prepared, in this regard, private and government industries, as well as universities, create an association to develop standards for I4.0.

Integrated Information Infrastructure Reference Model (I3RM) was proposed for digital manufacturing platforms (Fraile, Sanchis, Poler, & Ortiz, 2019). This model was created by combining different reference models to support the architecture of digital manufacturing platforms in practical use cases. Computer Integrated Manufacturing Open System Architecture (CIMOSA) is an architecture based on an event-driven approach to model company processes in a virtual world (Kosanke, 1991). International Society of Automation (ISA) 95 is an architecture paradigm that recognizes the need for industrial transition and offers guidelines focused on its own hierarchical structures of production processes to simplify the convergence of business functions and control systems (Lanza et al., 2016).

National Institute of Standards and Technology (NIST) (Liu et al., 2011) helps the smart manufacturing vision cope with the challenges of the I4.0 revolution that manufacturers have been experiencing in terms of quality, efficiency, and customized production. The architecture model was proposed for small- and medium-sized enterprises to integrate I4.0 and its standards to gain benefit from conformance testing, public documentation, and reference software implementations. Intelligent Manufacturing System Architecture (IMSA) (Wei, Hu, Cheng, Ma, & Yu, 2017) was developed to foster standardization by guiding the upgrade of Chinese manufacturing toward the I4.0 revolution. The smart manufacturing concept includes the implementation of machinery, new materials, new information technology, novel equipment, and numerical control tools as crucial characteristics to aid in the growth of China’s economy. IMSA is a guideline for constructing standards for manufacturing processes.

Industrial Internet Reference Architecture (IIRA) (Lin et al., 2017) is the first time issued in 2015 by the Industrial Internet Consortium (IIC). The Industrial Internet of Things (IIoT)-based reference model is used to design smart systems following the ISO 42010 standard by employing a standard lexicon and a standardized F/W (Fraile et al., 2019). Existing F/W models are listed in Table 2.4.

Table 2.4: Existing architecture models that guide the digital transformation of companies according to standards.

Architecture	I4.0 Technology	Architecture Layers	Architecture Levels	Life-Cycle Value Stream
CIMOSA (Kosanke, 1991)	IT Human–Machine Integration	Organization Resource Information Function	Generic Partial Particular	Requirement Definition Model Design Specification Model Implementation Description Model
RAMI 4.0 (Hankel & Rexroth, 2015)	Smart Mobility Smart Devices Smart Grid	Business Functional Information Communication Integration Asset	Product Field Device Control Device Station Work Centers Enterprise Connected World	Development Production
NIST (Liu et al., 2011)	Cloud Computing Interoperability Cybersecurity Internet of Things (IoT)	Privacy Security Cloud Services Management Service Orchestration Service Deployment	Application Middleware Operating System	Cloud Carrier Cloud Broker Cloud Provider Cloud Auditor Cloud Consumer
The National Institute of Standards and Technology Architecture (American National Institute of Standards and Technology, 2017)	Smart Manufacturing Cloud Computing	Cloud Transformation Model Ecosystem Manufacturing System	Product Production Business	-
IMSA (Wei et al., 2017)	Connectivity Cybersecurity	Business Patterns Information Fusion Interconnection System Integration Resource Elements	Equipment Control Workshop Enterprise Cooperation	Design Manufacture Logistics Sale Service
IIRA (Lin et al., 2017)	Cloud computing Containerization Infrastructure-as-a-Service (IaaS) Platform-as-a-Service (PaaS)	Business Usage Functional Implementation	Manufacturing Transportation Energy Healthcare Retail Smart Factory	Disposal Evaluation Operation Deployment Test/Validation Build Development Prototyping/Design Requirement Conceptualization

IBM I4.0 Reference Architecture (IBM, 2017)	Cybersecurity Cloud Computing	Equipment/Device Platform (Hybrid Cloud) Enterprise IT	Data Security Knowledge Devices Service Quality Network Configuration	Edge Plant Enterprise
SGAM (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012)	Smart Grid	Business Function Information Communication Component	Market Enterprise Operation Station Field Process	Customer Premises Distributed Electrical Resources Distribution Transmission Generation

Based on the analyzed F/W models literature, two major concerns are emphasized: the first is a lack of instructions for defining the areas that need to be tackled to implement I4.0, and the second is a lack of knowledge about how practically implement I4.0 after the areas have been defined. These two concerns lead to disruption between academia and industry. To provide a generic F/W that applies to real-world industries, the following questions should be answered by the F/W: where should we start implementing I4.0? how can a roadmap toward the industrial revolution be created? Therefore, a generic F/W model is required for practical uses; a generic F/W should be in line with modular MM dimensions and items.

2.5 Industry 4.0: Advantages and Benefits

I4.0 is imminent for the manufacturing systems of the future. Smart manufacturing enterprises can turn the fourth industrial revolution into an advantage. (BCG, 2017; EU, The Boston Consulting Group (BCG), & TUSISAD, 2016; Mittal, Khan, Romero, & Wuest, 2018; Özlü, 2017; PricewaterhouseCoopers (PWC), 2014b, 2015; Roland Berger, 2017; Schröder, 2016; Stark, Kind, & Neumeyer, 2017; Weyer, Schmitt, Ohmer, & Gorecky, 2015; Zhou, Liu, & Zhou, 2015) highlighted the following advantages of I4.0 for smart manufacturing enterprises as presented in Table 2.5.

Table 2.5: Advantages of I4.0.

Advantages	Authors
Productivity	(BCG, 2017; Holland Innovation Network, 2016; Mittal et al., 2018; PricewaterhouseCoopers (PWC), 2014b, 2015; Roland Berger, 2017; Tubitak, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017; Weyer et al., 2015; Wolter et al., 2015; Zhou et al., 2015)
Flexibility	(BCG, 2017; McKinsey Global Institute, 2015a; PricewaterhouseCoopers (PWC), 2015; Roland Berger, 2017; TUSISAD & The Boston Consulting Group (BCG), 2017; Wolter et al., 2015; Zhou et al., 2015)
Customer satisfaction	(Mittal et al., 2018; PricewaterhouseCoopers (PWC), 2014b; TUSISAD & The Boston Consulting Group (BCG), 2017; Wolter et al., 2015)
Networking	(PricewaterhouseCoopers (PWC), 2014b; Schröder, 2016; Schwab, 2018; Tubitak, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017; Wolter et al., 2015)
Quality	(EU, The Boston Consulting Group (BCG), et al., 2016; Roland Berger, 2017; TUSISAD & The Boston Consulting Group (BCG), 2017; Wolter et al., 2015)
Customized products	(EU, The Boston Consulting Group (BCG), et al., 2016; Roland Berger, 2017; TUSISAD & The Boston Consulting Group (BCG), 2017; Wolter et al., 2015)
Fast decision making	(EU, The Boston Consulting Group (BCG), et al., 2016; Roland Berger, 2017; Wolter et al., 2015)
Real-time information	(EU, The Boston Consulting Group (BCG), et al., 2016; Mittal et al., 2018)
Efficiency	(EU, The Boston Consulting Group (BCG), et al., 2016; Mittal et al., 2018; Özlü, 2017; PricewaterhouseCoopers (PWC), 2014b, 2015; TUSISAD & The Boston Consulting Group (BCG), 2017)
Economy	(Özlü, 2017; PricewaterhouseCoopers (PWC), 2014b; Schröder, 2016; Weyer et al., 2015)
Faster Production	(TUSISAD & The Boston Consulting Group (BCG), 2017)

Increase in productivity, flexibility, and quality has been emphasized as an advantage by many researchers (Holland Innovation Network, 2016; Mittal et al., 2018; PricewaterhouseCoopers (PWC), 2014b, 2015; Roland Berger, 2017; Tubitak, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017; Weyer et al., 2015; Wolter et al., 2015; Zhou et al., 2015). Some researchers (EU, The Boston Consulting Group (BCG), et al., 2016; Mittal et al., 2018) focused on real-time information as an advantage. Whereas (TUSISAD & The Boston Consulting Group (BCG), 2017) highlighted the importance of I4.0 in terms of faster production. It is very well understood that I4.0 offers various advantages for smart manufacturing enterprises.

2.6 Industry 4.0: Challenges

Although there are several benefits of the I4.0, as summarized in the previous section, there are also certain challenges associated with the adoption of I4.0, as studied by the researchers, (BCG, 2017; EU, The Boston Consulting Group (BCG), et al., 2016; PricewaterhouseCoopers (PWC), 2014b, 2015; Roland Berger, 2017; Schröder, 2016; Stark et al., 2017; Weyer et al., 2015; Zhou et al., 2015). The I4.0 revolution brings several challenges like slowing down of investments in capital-intensive systems, delaying of I4.0 technology integration due to limited skilled labor force, accelerating employer turnover, and delaying the formation of a qualified labor force. Placing special emphasis on training strategies for the formation of a qualified workforce that will be active in manufacturing can be considered a feasible strategy to overcome these obstacles (Öztürk, 2017).

Table 2.6 provides a summary of the challenges associated with the adoption of I4.0 technologies. (BCG, 2017; EU, The Boston Consulting Group (BCG), et al., 2016; Mittal et al., 2018; Özlü, 2017; Park et al., 2018; PricewaterhouseCoopers (PWC), 2014b, 2015; Stark et al., 2017; Zhou et al., 2015) have emphasized high investment cost as a major challenge in the adoption of I4.0 technologies.

Table 2.6: Challenges emphasized in recent research toward I4.0 adoption.

Challenges	Authors
Lack of standards and poor data security	(M. Correia & Silva, 2014; PricewaterhouseCoopers (PWC), 2014b; Schröder, 2016)
Lack of a digital strategy alongside resource scarcity	(Schröder, 2016)
Insufficient qualifications of employees	(Audit Tax Consulting Corporate Finance, 2015; Küsters, Praß, & Gloy, 2017; PricewaterhouseCoopers (PWC), 2014b)
Unclear economic benefits, excessive investments	(Küsters et al., 2017; PricewaterhouseCoopers (PWC), 2014b)
The low maturity level of required technologies	(PricewaterhouseCoopers (PWC), 2014b)

High investment cost.	(BCG, 2017; EU, The Boston Consulting Group (BCG), et al., 2016; Mittal et al., 2018; Özlü, 2017; Park et al., 2018; PricewaterhouseCoopers (PWC), 2014b, 2015; Zhou et al., 2015)
Higher network infrastructure.	(BCG, 2017; EU, The Boston Consulting Group (BCG), et al., 2016; Roland Berger, 2017)
Absence of digital culture.	(BCG, 2017; Özlü, 2017)
Unemployment rate	(Hawksworth, Berriman, & Goel, 2018)

(Hawksworth et al., 2018) recently reported an analysis of 29 countries including Turkey, in which the effect of automation on jobs is analyzed and forecasted. The study highlights existing jobs that might be at high risk of automation by the 2030s in terms of various industry sectors and occupations within industries. Furthermore, it provides a classification according to gender, age, and education level. In this research, automation is classified into three waves; algorithm wave concerns with simple computational tasks to make an intelligent analysis of structured data, augmentation wave; concerns with repeatable tasks to make automated and autonomy wave concerns with physical labor dexterity, interaction, and problem-solving in real-world circumstances. Hawksworth et al. (2018) reported that Turkey is among the top 12 countries that will be affected by automation, and 33% of jobs will be at high risk due to automation. It is claimed that Turkey is among the countries which are at the highest risk for autonomy wave (20%), whereas the risks for augmentation wave (12%) and algorithm wave (1%) are medium and low, respectively. Turkey may have relatively high exposure to later waves of automation that start to displace manual workers such as drivers and construction workers, but relatively lower exposure in the short term. The major effect will be the low educated workers in manufacturing and construction sectors.

2.7 Turkey: A Global Business, Manufacturing and Supply Chain Hub

Turkey is advantageously located at the junction of Europe, Asia, and the Middle East, surrounded by the sea on three sides and eight neighboring countries, and recognized as a regional hub for global business, both in terms of production and distribution. Member of the Organization for Economic Co-operation and Development (OECD), The North Atlantic Treaty Organization (NATO), and The Group of Twenty (G20) and a candidate for European Union (EU) since 1999, Turkey's proximity to European business ethics and participation in the global scene are major assets for investors. Additionally, Turkey has a Customs Union with the European Union since 1996 and several trade agreements with worldwide countries.

Over the last decade, the Turkish economy has shown noteworthy performance with its steady growth, becoming the 17th largest economy in the world. Turkey remains one of the most attractive investment destinations that recovered well from the global crisis of 2008/09 due to structural reforms. The economy registered average annual growths of 4% over 2002 to 2016 and 2.9% end of 2016 (Özlü, 2017). Recently, sluggish growth in Europe and a deteriorating geopolitical environment in its neighborhood have negatively influenced exports, investment, and growth as presented in Figure 2.3. The recent influx of 3 million Syrian refugees has created new socio-economic and political challenges, particularly in urban centers. Despite all these difficulties, Turkey has set challenging goals for 2023. Turkey has been successful in attracting foreign investments in 2016. In December, The International Finance Corporation (IFC) announced an investment of USD 85.3 million in a project bond to support the construction of next-generation health care facilities, after it has realized a record investment of USD 1.3 billion in 2015 for 28 projects. Lately, in January 2017, Turkey allured investments with a new USD 20 billion Turkish-Gulf fund, which is the second one from the Middle East and North Africa (MENA) region after the Qatari fund (Switzerland Global Enterprise, 2017).

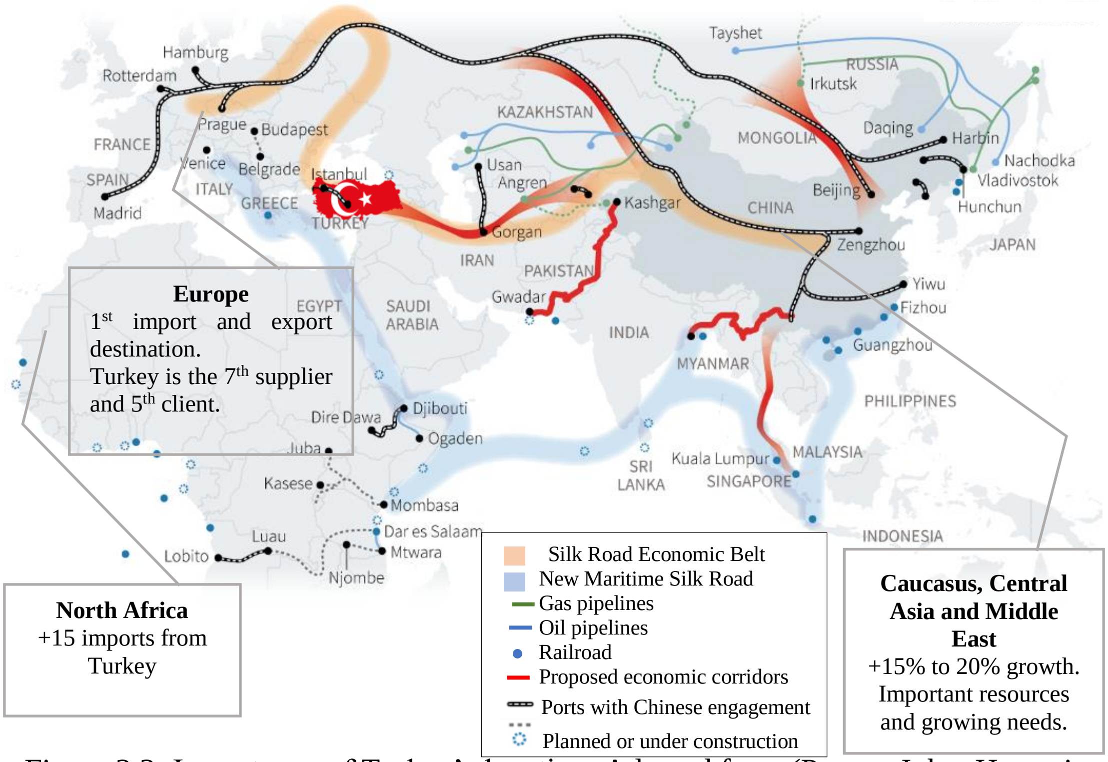


Figure 2.3: Importance of Turkey’s location. Adapted from (Putten, John, Huotari, Ekman, & Otero-Iglesias, 2016; Switzerland Global Enterprise, 2017).

To prove its resilience, the government did not give up on mega-projects launched a few years ago and 2 big projects were finalized and inaugurated in 2016 - the 3rd Bosphorus Bridge and the Eurasia Tunnel that links the European and Asian parts of Istanbul under the sea. Transport and communication infrastructure have substantially developed in the recent decades due to large-scale programs and efficient investments. Many new airports have been already built in Turkey. A new airport is bringing the total number to 57, with seven new airports planned within the national program. New Istanbul Airport is envisaged as the World’s largest airport with a 150 million annual passenger capacity, upgradable to handle 200 million annual passengers. The third international airport built and now operational in Istanbul besides Atatürk and Sabiha Gökçen airports, and is envisaged to become the main international airport (Star Newspaper, 2013). In parallel, the development of the railway network accelerated through the privatization of the National Railway Directory. All these initiatives contributed towards Turkey becoming one of the countries with the largest upper-middle-class income in its region (Switzerland Global Enterprise, 2017).

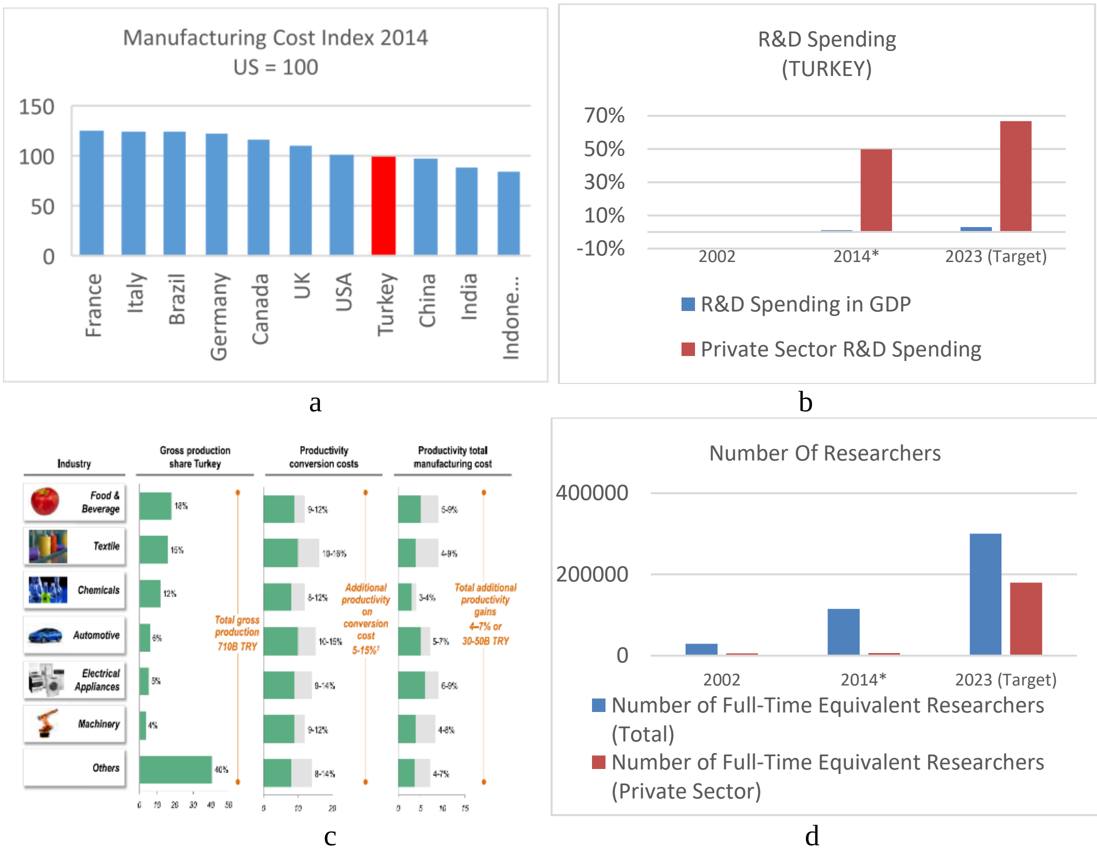


Figure 2.4: Analyzing Turkey’s status. Adapted from (The Boston Consulting Group (BCG) & TUSISAD, 2016). a) Turkey’s position in the global value chain, b) Turkey targets for R&D spending, c) Industrial production and productivity distribution of Turkey, d) Turkey targets for the number of researchers.

According to TUSISAD and The Boston Consulting Group (BCG) (2017) and (The Boston Consulting Group (BCG) & TUSISAD, 2016) reports, Turkey has a competitive advantage in the global value chain owing to its geographical location providing logistic advantage, and relatively lower labor costs. According to BCG Global Manufacturing Cost Index, based on manufacturing costs, productivity, and exchange rates, Turkey manufactures at an average unit cost of 98 while the USA at an average unit cost of 100, and Germany at an average unit cost of 121. Direct manufacturing costs in Turkey are 23% and 2% below compared to Germany and the USA, respectively. Despite this cost advantage, Turkey ranks 55th in the Global Competitiveness Index Report. Turkey has an average position in the global value chain compared to other countries as presented in Figure 2.4 (a). Food and beverage, textile, chemical, automotive, electrical appliances and machinery industries present a higher impact on Turkey's productivity as shown in Figure 2.4 (c). Moreover, R&D spending and the number of researchers are presented in Figure 2.4 (b) and Figure 2.4 (d) to highlight Turkey's target and ongoing researches based on Turkey's roadmap.

Almost half of the products in Turkey are manufactured with low technology. Also, more than half of the nationwide initiatives are made up of low-technology entrepreneurs. On the other hand, the share of high-technology products in Turkey's exports is around 4%, in comparison to South Korea, which is 30%, and 15% in the European Union (EU), (EU, The Boston Consulting Group (BCG), et al., 2016). Turkey needs to increase the per kilogram value of its exports. For instance, as a comparison, in terms of per kilogram value, Turkey gives back export revenues obtained with tomato exports, with an import of mobile phones. Turkey exports tons of truckloads of marble and imports a single truckload of medicines. Another example of a comparison is that Turkey manufactures and exports a bus, in return, imports an artificial heart, which weighs less than one kilogram having almost equivalent prices (T. Yildiz, 2017). The top twenty-mega companies across various industries are shown in Figure 2.5. It is well understood that private companies, as well as private sector companies, have a critical impact on technology.

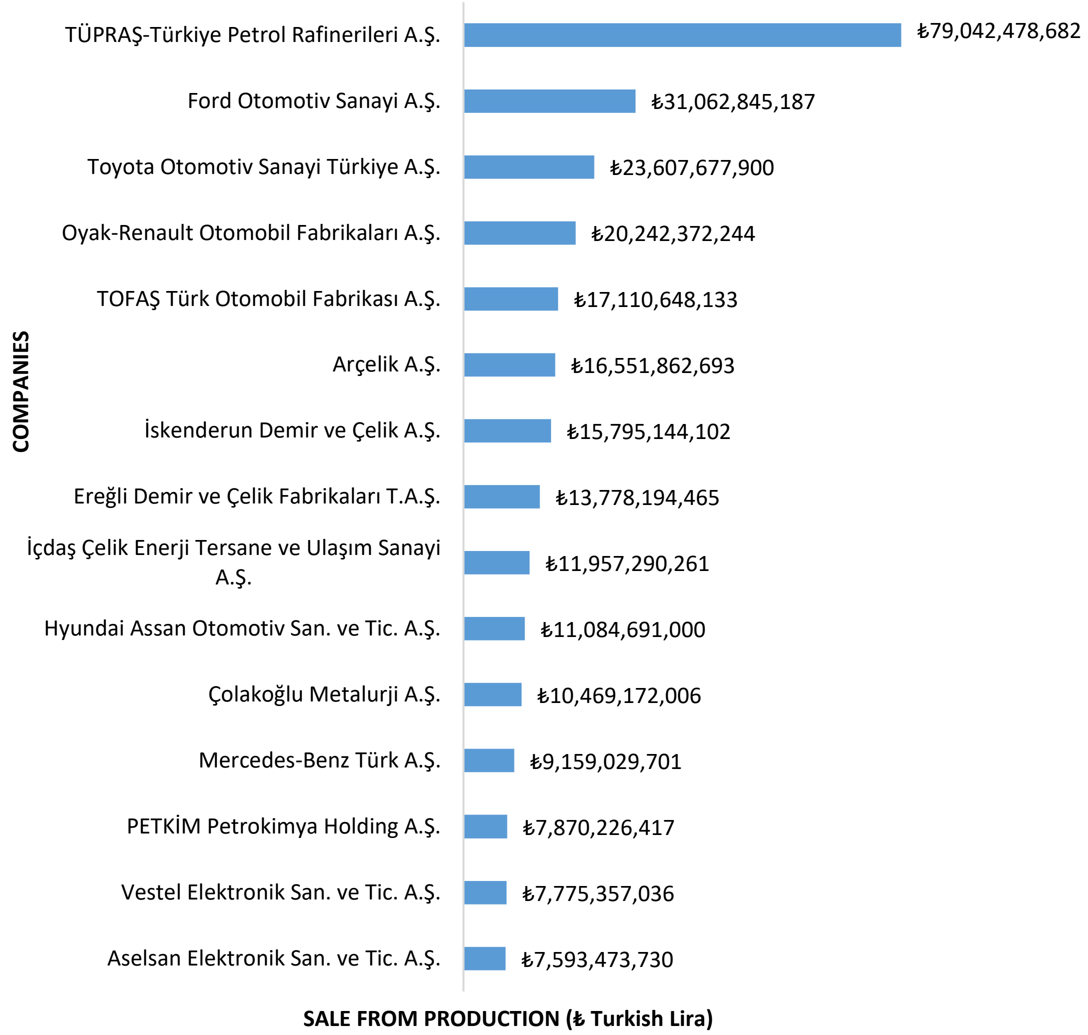


Figure 2.5: Mega companies in Turkey (Istanbul Chamber of Industry, 2018).

The workforce in Turkey is one of the youngest and largest in Europe. Education and training programs are following the ever-growing Turkish industry, and recognized universities are churning out highly qualified personnel who sustain innovation in the private and government sectors. A domestic market of approximately 80 million in Turkey enables investors/businesses to reach a fast-growing regional market (Özlü, 2017). Turkey is a resilient economy despite internal and external chocks and offers many assets for investors. With a fast penetration of digital technologies in the last few years, the Turkish population ranks among the major users of social media and mobile technologies in the world. This young, highly connected, and consuming population makes Turkey an attractive domestic market for companies willing to sell innovative products, and target young and curious consumers with improving income levels.

Due to an affordable and qualified workforce and Turkey’s will to become a high added value products exporter, it offers many opportunities for outsourcing and technology transfers as well. The Turkish government is proactive to facilitate broader development and entail higher public and private investment and skilled job creation, taken several sectorial reforms and offered many incentives per sector of activity. Turkey is also part of several subsidy and development programs allowing research and development cooperation for European companies in several fields. As an industrialized and fast emerging country, Turkey is indeed trying to catch up with highly developed countries, especially for innovative high value-added products, and is therefore investing in R&D. Turkey has set a route map until 2023, the centenary of the Republic to improve its infrastructure and boost strategic sectors (Holland Innovation Network, 2016). In this context, foreign investors are welcomed to bring their knowledge into the market and collaboration opportunities are high in many sectors, especially in four strategic sectors; transports, defense, healthcare, and new technologies and information systems. Digital and smart technologies are necessary for the county’s future welfare and sustainable growth. The concept of factory 4.0 is presented in Figure 2.7.

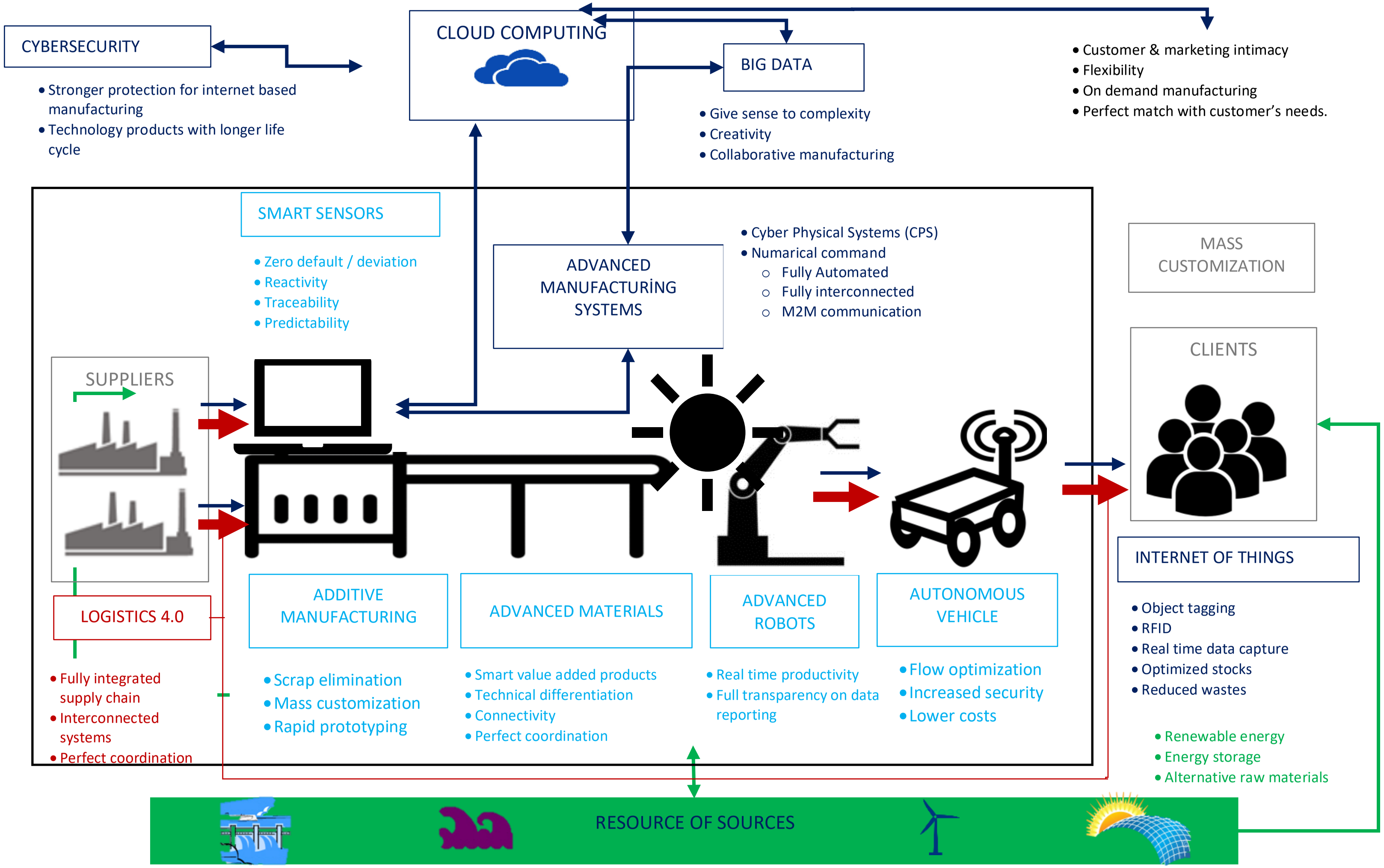


Figure 2.6: An overview of factory 4.0 (Cinar, Z.M. et al. 2019).

2.8 Recent Research on Turkey in the Context of Industry 4.0

Presently studies based on I4.0 are a hot trend and researchers are focusing on this revolution. Most of the researchers published their studies for awareness of I4.0 as well as consideration are taken to realize the readiness of Turkey for the industry 4th revolution. Implementation of I4.0 provides significant benefits as well as challenges. Mostly these studies focused on efficiency, innovation, global competitiveness, labor cost, quality, and productivity (Allenhof, 2015; Bychkov, Guts, & Gordon, 2017; M. Correia & Silva, 2014; IMPULS, 2015; Intepe, 2016; Jaramillo, 2014; Kucharavy & De Guio, 2011; McKinsey Global Institute, 2015a, 2018; Özlü, 2017; PricewaterhouseCoopers (PWC), 2016; Siemens, 2016; Taymaz, 1997; The University of Warwick (WMG), 2017; UNIDO, 2017; Yalçın, 2018; Zhong, Xu, Klotz, & Newman, 2017). Nevertheless, these advantages of I4.0 are not sufficient to consider implementing I4.0 due to the presence of challenges that the I4.0 revolution brings. Recruiting and developing new talent, formation of an experienced workforce, and high capital investments are highlighted as challenges. Recruiting & developing new talent and the formation of an experienced workforce may cause an increase in unemployment.

Figure 2.8 elaborates the exponential growth trend in the number of publications on I4.0 in Turkey. The number of articles related to I4.0 and its key technologies in the world has started rising in 2009-2010. However, there are still no enough publications in the literature related to I4.0 and its key technologies in Turkey. It is also an interesting fact that not only Turkish universities follow I4.0 in Turkey, there are also researchers in Germany concerned with the development of I4.0 in Turkey. Overall, it is well understood that there are relatively few numbers of publications related to I4.0 and Turkey.

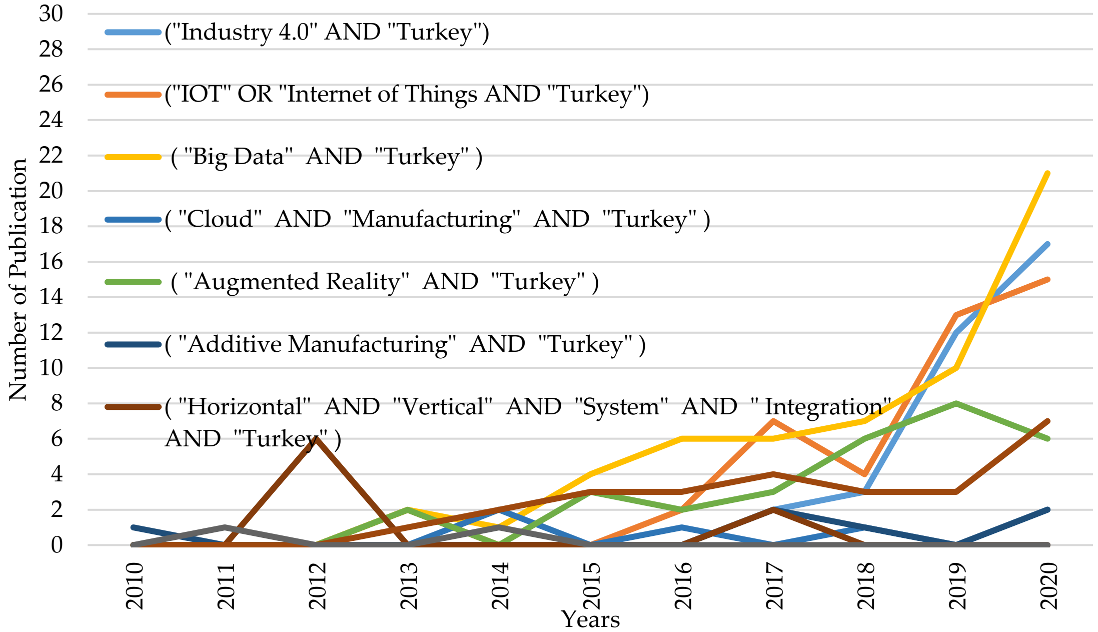


Figure 2.8: Statistics from Scopus database (Date: 16.03.2021), Published documents per year over Turkey with keywords: (“Industry 4.0” AND “Turkey”), (“IoT” OR “Internet of Things” AND “Turkey”), (“Big data” AND “Turkey”), (“Cloud” AND “Manufacturing” AND “Turkey”), (“Augmented reality” AND “Turkey”), (“Additive manufacturing” AND “Turkey”), (“Horizontal AND “Vertical” AND “System” AND “Integration” AND “Turkey”), (“Cyber-Security” OR “Cybersecurity” AND “Turkey”), (“Simulation” AND “Industry 4.0“ AND “Turkey”).

Table 2.7 classifies the recent research on I4.0 Technologies in Turkey and it is highlighted that many researchers (Baena, Guarin, Mora, Sauza, & Retat, 2017; Balasingham, 2016; Burma, 2016; Bychkov et al., 2017; Esengün & Ince, 2018; Fischer, 1994; Gamboa-Revilla & Ramirez-Cadena, 2008; Gökalp et al., 2017; Karre, Hammer, Kleindienst, & Ramsauer, 2017; Kiang, 2016; Li & Si, 2017; McKinsey Global Institute, 2015b; Nilsen & Nyberg, 2016; Onar, Ustundag, Kadaifci, & Oztaysi, 2018; Özkurt, 2016; Puhtila, 2018; Roland Berger, 2017; L. M. Sanchez & Nagi, 2001; Sarvari, Ustundag, Cevikcan, Kaya, & Cebi, 2018; Stock & Seliger, 2016; The Boston

Conculting Group (BCG), 2016; The Boston Consulting Group (BCG), 2016b; Uhlemann, Schock, Lehmann, Freiberger, & Steinhilper, 2017; Yuksel & Sener, 2017) have focused on Intelligent manufacturing, IoT and cloud computing. However, few researchers (Ivanov, Sokolov, & Ivanova, 2016; Karaköse & Yetiş, 2017; Kasapoğlu, 2017; J. Lee, Bagheri, & Jin, 2016; Leitão, Colombo, & Karnouskos, 2016; PricewaterhouseCoopers (PWC), 2015; Weber, Königsberger, Kassner, & Mitschang, 2017) have focused on cyber security systems and Horizontal and Vertical Systems.

Table 2.7: Recent researches classified according to I4.0 technologies.

I4.0 Technologies	Major Characteristics and Key Technologies	References
Intelligent Manufacturing	• AI-based smart decision making • Advanced automotive production • Adaptive and flexible manufacturing systems • Manufacturing execution system (MES) • Smart manufacturing planning	(Baena et al., 2017; Balasingham, 2016; Barclays, 2017; Burma, 2016; Bychkov et al., 2017; Esengün & Ince, 2018; Fischer, 1994; Gamboa-Revilla & Ramirez-Cadena, 2008; Gökalp et al., 2017; Karre et al., 2017; Kiang, 2016; Li & Si, 2017; McKinsey Global Institute, 2015a; Nilsen & Nyberg, 2016; Özkurt, 2016; Puhtila, 2018; Roland Berger, 2017; L. M. Sanchez & Nagi, 2001; Stock & Seliger, 2016; The Boston Conculting Group (BCG), 2016; The Boston Consulting Group (BCG) & TUSISAD, 2016; Uhlemann et al., 2017; Yuksel & Sener, 2017)
Big Data	• Internet of things • Cloud manufacturing • Simulation • Big data analytics • Big data processing	(Karlberg & Pettersson, 2016; J. Lee, Kao, & Yang, 2014; Tao, Qi, Liu, & Kusiak, 2018; Wang, Wan, Zhang, Li, & Zhang, 2016; S. Yin & Kaynak, 2015)
Augmented Reality	• Virtualization method • Overlay of real and digital world • Real-time interaction • Registration and alignment in 3D	(Almada-Lobo, 2016; Esengün & Ince, 2018; Funk, Kosch, Kettner, Korn, & Schmidt, 2016; Vuksanović, Ugarak, & Korčok, 2016)
Additive Manufacturing	• Circular economy management • Predicted error proofing	(McKinsey Global Institute, 2015b; Roland Berger, 2017; Stock & Seliger, 2016; Tubitak, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017)
Cloud Computing	• Manufacturing service distribution and sharing • Intelligent capability management • Manufacturing cloud service management • Internet of things	(McKinsey Global Institute, 2015b; Mourad, Nassehi, & Schaefer, 2016; PricewaterhouseCoopers (PWC), 2016; Puhtila, 2018; The Boston Consulting Group (BCG), 2016b; Tran, 2016; Tubitak, 2016)
Horizontal and Vertical Systems	• Universal data integration networks • Automated value chains	(Boston Consulting Group (BCG), 2015; PricewaterhouseCoopers (PWC), 2016; Weber et al., 2017)
Cyber Security	• Auto-ID technology-based smart manufacturing • Smart communication / collaboration • I4.0 ethical standards • Innovative problem solving	(Ivanov et al., 2016; Karaköse & Yetiş, 2017; Kasapoğlu, 2017; J. Lee et al., 2016; Leitão et al., 2016)

Internet of Things	• Real-time data manufacturing and decision making • Real-time visibility and traceability of production processes • Wireless production • Real-time data collection • RFID enabled real-time production planning and scheduling system	(Almada-Lobo, 2016; Funk et al., 2016; Isikli, Yanik, Cevikcan, & Ustundag, 2018; Karlberg & Pettersson, 2016; Montanus, 2016; Pazvant & Faiz, 2018; Vuksanović et al., 2016; Yuksel & Sener, 2017)
Simulation	• Virtualization method • Intelligent product analytics • Smart monitoring behavior or physical properties of products/processes	(Arendt, 2012; Faheem & Gungor, 2018; Kukushkin et al., 2016; Martino, 2003; Nagadi, 2016; Negahban & Smith, 2014; Onar et al., 2018; Uhlemann et al., 2017)
Autonomous Robots	• Advanced robotics • Collaborative robotics • Decision making	(Baldassarre, Ricciardi, & Campo, 2017; Bayram & Ince, 2018; Busi et al., 2017; Fye, Charbonneau, Hay, & Mullins, 2013; Kasapoğlu, 2017; Ostergaard, 2017; A. Yildiz, 2018)

(The Boston Consulting Group (BCG) & TUSISAD, 2016) collaborated and conducted in-depth interviews with 25 manufacturers operating in six different sectors in Turkey. The results indicate that the potential benefits of Turkey's I4.0 transformation in the pilot sectors are productivity and cost increase. The report states that it is possible to increase productivity 10-15% in the automotive sector, 9-14% in the white appliances sector, 10-16% in the textile sector, 8- 12% in the chemical sector, 9-12% in the food and beverage sector and 9-12% in the machine sector. According to the same report, the cost increase is expected to be 5-7% in the automotive sector, 6-9% in the white appliances sector, 4-9% in the textile sector, 3-4% in the chemical sector, 5-9% in the food and beverage sector, and 4-8% in the machine sector in the form of productivity increase.

Table 2.8 presents a classification of the recent research according to Industrial Sectors in Turkey. It can be understood that many researchers, (Audit Tax Consulting Corporate Finance, 2015; Aydemir, 2018; Bulut & Akçacı, 2017; Genc, 2018; Koca, 2018; Özlü, 2017; Öztürk, 2017; Sak & Inan, 2015; Switzerland Global Enterprise, 2017; The Boston Consulting Group (BCG), 2016a; Tubitak, 2016; Tuncel & Polat, 2016; A. Yildiz, 2018) focused on I4.0 adoption in manufacturing. However, a few researchers highlighted I4.0 adoption to heath care, e.g. Özlü (2017).

Table 2.8: Recent research classified according to Industrial Sector.

Industrial Sectors	Supporting Technologies	References
Automotive	• Laser-guided - Automated guided vehicles (AGV) • Virtual factory and product design.	(Gabaçlı, 2017; The Boston Consulting Group (BCG) & TUSISAD, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017)
Textile	• RFID Transponder. • Interfaces between process steps. • Virtual modeling.	(Aegean Region Chamber of Industry, 2015; Genc, 2018; Ovaci, 2017; Özkurt, 2016; Sak & Inan, 2015; Soyak, 2017)
White appliances	• Smart products.	(Bychkov et al., 2017; EU, The Boston Consulting Group (BCG), et al., 2016)
Commerce & Logistic	• Automated storage systems.	(Gros & Selçuki, 2013; Özlü, 2017; Şekkeli & Bakan, 2018; Switzerland Global Enterprise, 2017)
Transportation	• Autonomous vehicles. • Automated guided vehicles (AGV). • Innovative services relating to different modes of transport and traffic management.	(Özlü, 2017; Şekkeli & Bakan, 2018; Switzerland Global Enterprise, 2017)
Food & Beverage	• Reduce cost through real-time production control across the entire plant. • Visualization of data.	(The Boston Consulting Group (BCG) & TUSISAD, 2016)
Manufacturing	• Autonomous robots. • Collaborative robots. • Fully automated/smart factories	(Aydemir, 2018; Bayram & Ince, 2018; Bulut & Akçacı, 2017; Genc, 2018; Koca, 2018; Öztürk, 2017; Sak & Inan, 2015; Switzerland Global Enterprise, 2017; Tubitak, 2016; Tuncel & Polat, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017; A. Yildiz, 2018)
Education	• New ways of communicating. • Simulation-based learning. • Virtual assistants and instructors.	(Onar et al., 2018; Özlü, 2017; A. Yildiz, 2018)
Healthcare	• Universal connectivity. • Improve monitoring of patients, applying personalized treatment plans, and predictive medicine.	(Özlü, 2017)
Communication	• Efficient use of resources. • Integrating customers and business partners into the business. • Cyber-physical systems.	(Şekkeli & Bakan, 2018)
Power Systems	• Wireless power transmission. • Equipment connectivity. • Intelligent drive and provides real-time machine performance.	(Ozlu, 2017)
Chemical	• Self-optimizing process flow	(The Boston Consulting Group (BCG) & TUSISAD, 2016)

Turkey’s world competitiveness ranking in terms of knowledge, technology, future-readiness, and overall competitiveness trend for 5 years (2014, 2015, 2016, 2017, and 2018) are presented in Table 4. Furthermore, Factors and sub-factors affecting competitiveness are published in 2018. IMD Digital Competitiveness Center (2020), studied all factors including the sub-factors of world countries and then reported the competitiveness ranking of each country. Out of 53 countries, Turkey’s overall ranking is 52 in 2018, as shown in Table 2.9 as well as Figure 2.9.

Table 2.9: Global competitiveness rankings for I4.0 over 63 countries. Source: (IMD Digital Competitiveness Center, 2020).

Turkey’s Performance over The World						
FACTORS	2014	2015	2016	2017	2018	2019
Overall	52	52	50	52	52	52
Knowledge	59	59	58	60	59	60
Technology	47	48	48	49	45	48
Future readiness	44	42	42	40	42	41

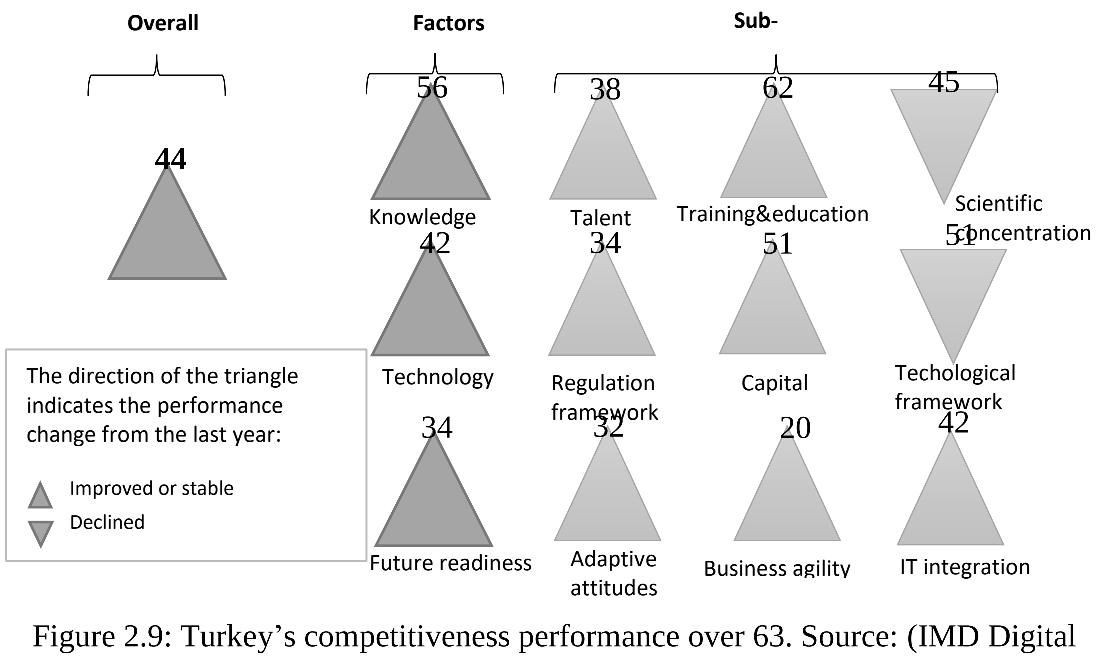


Figure 2.9: Turkey’s competitiveness performance over 63. Source: (IMD Digital Competitiveness Center, 2020).

2.9 Industry 4.0: Turkish Government's Approach and Initiatives

Turkey has been subjected to critical changes in several areas. Despite the economic crises and instability, Turkey has successfully managed to grow year by year, and it is often cited as one of the fast-growing economies in the world. Turkish government aims to be among the 10 largest economies in the world by 2023. The trades and industrial structures require technological developments to include value-added products and especially demanded products. Turkey must overcome competitive pressures such as Customs Union (CU) and Free Trade Agreements (FTAs) regulations related to trade with third countries (Gros & Selçuki, 2013). Turkey is a young populated country with medium-level technology and a growing workforce. Turkey has the potential to change its role in the global economy if a huge transformation to the fourth industrial revolution is achieved. It is important and urgent that all stakeholder's attention to work within the joint national plan towards the I4.0 revolution. (EU, The Boston Consulting Group (BCG), et al., 2016; Holland Innovation Network, 2016; Schröder, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017) reported the current status of Turkey in the light of I4.0 and identified the roadmap to success. It is found that I4.0 will be a very important factor that can be turned into an opportunity to enhance the development as well as the competitiveness of the Turkish industry. In this regard, Turkey can take its place among the leading nations. Identifying the requirements of I4.0 is one of the crucial actions to take for Turkey. In this way, Turkey can turn this revolution into an opportunity. To do this, there is a strong requirement to develop a roadmap towards the industrial revolution (Holland Innovation Network, 2016).

T. Yildiz (2017) conducted a 12-pillar global competitiveness study on the relationship between awareness of I4.0 in The International Student Assessment Program (PISA) and the global competitiveness of Turkey. Statistical analysis carried out and the regression value obtained accounts for 32% of the variability of the relationship between them. In terms of PISA success, coefficients of Mathematics, Reading, and Science are 3.67, 2.33, and 5.94 respectively. It is investigated that there is a significant relationship between the global competitiveness index and global success in education. It should not be forgotten that as a result of the international PISA test, Turkey ranks 50th in a level that is very low among 72 countries. According to the results of the International PISA test, students in Turkey are below The Organization for Economic Co-operation and Development (OECD) (T. Yildiz, 2017).

Kılıç and Alkan (2018), studied within the frame of Turkey's 2023 vision, Research and Development (R&D) expenditures in the World and Turkey, production and exploration of high value-added, technology-intensive industrial robots, and employment of R&D personnel in the scope of I4.0 revolution. A comprehensive study on industrial robot production carried out and yearly industrial robot production. Moreover, their study showed that China is the country where the highest number of industrial robotics is produced yearly. There are approximately 200 automation companies available in Turkey and investment in R&D is essential to implement fourth revolution technologies to Turkish companies. Thus, it is concluded that Turkey is capable to implement I4.0.

I4.0 is relatively new in Turkey as the concept arrived in Turkey in 2015 and adoption started with the automotive industry. In December 2015, the Public sector gave the signal of I4.0. Projects and guidelines are created to encourage industries to be part of this industrial revolution. The number of events and projects are multiplied recently compared to 2015 (Özlü, 2017). Turkey has developed a model based on public-private cooperation to accelerate the process of digital transformation in the industry and established the Digital Transformation Platform. A new platform is created to encourage industries for I4.0, as well as to focus on Turkey's priorities. Union of Chambers and Commodity Exchanges of Turkey (TOBB), Turkish Exporters Assembly (TİM), Turkish Industry and Business Association (TÜSİAD), Independent Industrialists' and Businessmen's Association of Turkey (MÜSİAD), The International Investors Association of Turkey (YASED), Technology Development Foundation of Turkey (TTGV), and other six working groups are brought together under the leadership of Turkish Ministry of Science (Özlü, 2017).

The Turkish government provides direct support for R&D through ecosystems and sets important targets for 2023, the centenary of the Turkish Republic (PricewaterhouseCoopers (PWC), 2015). It is observed that the young population of Turkey and potential business in Turkey due to its geographical location are significant advantages to implement I4.0. Also, rapid export growth, a large domestic market, and generous public incentives are Turkey's strengths for I4.0. Awareness and knowledge of I4.0 in the context of Turkey is not yet well understood due to insufficient research. Substantial challenges, barriers, and major concerns for I4.0 adoption in Turkey were found as higher-skilled labor force, premature de-industrialization risk, and low export share of high-technology products.

Sung (2018) proposed four necessary steps for successful transformation towards I4.0 as; (1) refine and expand the government's strategies for creating flexible economic and social structures that can respond to change, (2) establish operational structures to optimize the policy effectiveness, (3) create practical road maps to transition towards economic and social systems that can accommodate innovative changes, and (4) establish infrastructure to lead all initiatives. The Turkish government is well aware of the significance of adopting I4.0, and has taken sincere policy initiatives, and demonstrated strong resolve in the adoption and development of I4.0 technologies to meet the challenge. Table 2.10 summarizes some of the initiatives of the Turkish government.

Table 2.10: Turkey's initiatives toward the I4.0 revolution. Adopted from (MUSISAD, 2017; Özlü, 2017; Sak & Inan, 2015; The Boston Consulting Group (BCG) & TUSISAD, 2016).

Turkish Government	Initiatives
Independent Industrialists' and Businessmen's Association of Turkey (MÜSİAD)	• Supports SMEs and collaboration between private and public sectors.
Machinery Exporters Union	• Prepare a guide for Turkish manufacturers in partnership with German VDMA at the WIN Automation Fair occasion.
The direction of Technology and Innovation Support Programs (TEYDEB)	• Subsidiaries for I4.0 projects about advance manufacturing technologies, multilayer additive manufacturing technologies, Computer aid system design and development, simulation modeling software, robotics and mechatronics, FMS, IoT, virtualization, M2M communication, and cloud computing.
Scientific and Technological Research Council of Turkey (TUBITAK)	• Increasing I4.0 awareness at public and private companies/Universities. • Improving the private sector's ability to transform. • Identifying and supporting relevant research topics. • Promoting the I4.0 platform as an effective communication media for all stakeholders. • Increasing international cooperation.
Decrees of Supreme Council of Science and Technology	• Development of monitoring model for smart manufacturing in which stakeholders connected each other. • Increase in goal-oriented R&D such as cyber-physical systems, Sensors and robotics, IoT big data, and cloud computing technologies. • Creation of support mechanism for manufacturing substructures to develop critical technologies.

The Union of Chambers and Commodity Exchanges of Turkey (TOBB) Turkish Exporters Assembly (TİM) Independent Industrialists' and Businessmen's Association of Turkey (MÜSİAD) The International Investors Association of Turkey (YASED) Technology Development Foundation of Turkey (TTGV) Turkish Industry and Business Association (TUSISAD)	• Create an association with six working groups to emphasize many targets for the changing of Turkish industry toward to 4rt industrial revolution. • Establish infrastructure to lead all initiatives.
Istanbul Metropolitan Municipality	• Dedicated to work on smart building and smart energy projects.
Ministry of Finance	• The use of infrastructure investments for promoting strategic investment involving critical technologies. • Use of public procurements for improving the innovation and green production capacity of domestic firms. • The improvement of export capacity in smart building technologies, public transportation, and signaling systems. • The efficient use of country loan and guarantee programs for increasing the export of capital goods. • Subsidizing the acquisition of foreign companies.
Ministry of Industry and Technology	• Prepare a road map of I4.0 for Turkey. • Build economic and social systems that can respond to changes. • Establish an operational system to maximize the effectiveness of initiatives and policies.

Table 2.11 encapsulates private companies towards the I4.0 in Turkey, but these companies require a very high level of coordination among all the stakeholders.

Table 2.11: Turkish private companies toward the I4.0 revolution (Öztürk, 2017).

Sector	**Company**
Mobile & TV & White goods, Electronics	Samsung, Panasonic Eco Solutions, Vestel, Arçelik Inc., Zorlu Holding
Automotive Industry	CMS Wheel and Machine, SGS Automation and Drive, Ermaksan, Frekans Mech., Lodos Technical
Software	Boğaziçi Software, MCS, Artesis
Energy and Textile	Başöz Energy, Çalık Holding
Defense & Software Industry	Havelsan, Aselsan
Steel & Distributorship & Energy & Logistics	Borusan
Glass Manufacturing	Şişecam
Telecommunications Industry	Turkcell
Pharmaceutical	Eczacıbaşı
Bottling Facilities Manufacturing	Ektam
Machinery Manufacturing Industry	Volkan Engr.

There are a few companies that have already started implementing I4.0 (Kahraman, 2018). The companies are shown in Table 2.12.

Table 2.12: Companies leading I4.0 in Turkey (Kahraman, 2018).

Company	Sector	Product
SIEMENS	Conglomerate	• Electrification • Automation • Digitalization
BOSCH	Conglomerate	• Automotive components • Industrial technology • Consumer goods • Power tools
GE	Conglomerate	• Acquisitions and divestments • Computing • Power generation
FESTO	Electronics	• Pneumatic • Electrical control systems
MITSUBISHI ELECTRIC	Electrical Equipment Electronics	• Building Systems • Communication Systems • Industrial Automation • Medical Systems • Power Systems

2.10 Turkey’s Smart Manufacturing Roadmap

I4.0 is a vision that describes the industry of and for the future, moving towards higher productivity with flexibility, making it possible to manufacture highly individualized products under the economic conditions of mass production. Since its introduction in Germany, I4.0 is now a worldwide concept. Because of the significance of this change on a country’s place in a global economy, several governmental policies have been implemented all around the globe to expedite the transition. China, the USA, and many EU countries are leading the race. The world is on the brink of I4.0, and there is an intent to implement I4.0. The global manufacturing industries are still in the progress of discovering the benefits and challenges of I4.0.

Turkey with the geostrategic location at the junction of Europe, Asia, and the Middle East, is recognized as a regional hub for global business, both in terms of production and distribution. I4.0 is relatively new in Turkey as the concept arrived in Turkey in 2015. Turkey has developed a model based on public-private cooperation to accelerate the process of digital transformation in the industry and launched several programs and given subsidies for I4.0 projects. The Turkish government is well aware of the significance of adopting I4.0 and has taken policy initiatives and decisions towards the fourth industrial revolution, but these initiatives require a very high level of coordination among all the stakeholders.

The principle concept of I4.0 raised and implementation of 4rt industrial revolution to middle and large enterprises has been started in the industry. In academic literature, applications, advantages, challenges, awareness, and readiness of Turkey are discussed. The research on I4.0 technologies has increased significantly over the last decade. Recently, researchers have studied the adoption of I4.0 technologies in Turkey, and have highlighted the advantages and challenges associated with it. However, mostly their research is limited to few industrial sectors; Automotive (Gabaçlı, 2017; The Boston Consulting Group (BCG) & TUSISAD, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017), textile (Aegean Region Chamber of Industry, 2015; Genc, 2018; Ovaci, 2017; Özkurt, 2016; Sak & Inan, 2015; Soyak, 2017), white appliances (Bychkov et al., 2017; EU, The Boston Consulting Group (BCG), et al., 2016), manufacturing (Audit Tax Consulting Corporate Finance, 2015; Aydemir, 2018; Bulut & Akçacı, 2017; Genc, 2018; Koca, 2018; Öztürk, 2017; Sak & Inan, 2015; Switzerland Global Enterprise, 2017; Tubitak, 2016; Tuncel & Polat, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017; A. Yildiz, 2018), food and beverage (The Boston Consulting Group (BCG) & TUSISAD, 2016).

Moreover, (BCG, 2017; EU, The Boston Consulting Group (BCG), et al., 2016; Mittal et al., 2018; PricewaterhouseCoopers (PWC), 2014b, 2015; Roland Berger, 2017; The Boston Consulting Group (BCG) & TUSISAD, 2016; TUSISAD & The Boston Consulting Group (BCG), 2017; Weyer et al., 2015; Zhou et al., 2015) have highlighted productivity and quality. Also, (Audit Tax Consulting Corporate Finance, 2015; Küsters et al., 2017; PricewaterhouseCoopers (PWC), 2014b) have recognized the formation of an experienced workforce, as the biggest challenges in the adoption of I4.0. Actual and potential benefits from adopting I4.0 are observed as an increase in production, increase in mass customization, increase in flexibility, increase in productivity, increase in customer services, and creation of new different business models. I4.0 enablers pave the way for a tectonic change in Turkey's economic competition, resulting in a larger share of the global supply chain with increased employment of qualified labor force. Hawksworth et al. (2018) reported that jobs at risk due to automation and Turkey may need to slow down its industrial transformation to automation unless there is a significant growth in the highly-skilled and educated workforce. Benešová and Tupa (2017) identified the qualification and skills requirements for people in I4.0 and emphasizes the need for Informatics Specialists, PLC Programmer and Robot Programmers, Software Engineers, Data Analysts, Cyber security experts, Electronics and Automation Technician, Production Technician, and Manufacturing Engineers.

The adoption of I4.0 is being taken seriously in Turkey, as it presents an opportunity to advance Turkey's economy. The inability of I4.0 adoption may lead the Turkish manufacturers to disruption. The transition can be smooth or disruptive depending upon the coherence between the key stakeholders. To ensure a speedy and smooth transition towards I4.0, the Government, universities, and manufacturers, must take joint initiatives to develop a multi-pronged strategy to expedite the awareness and capacity building for the adoption of I4.0 technologies:

- Conduct research surveys, interviews encompassing all key stakeholders to determine the status, identify the strengths, competencies, weaknesses, needs, gaps, and challenges associated with the adoption of I4.0 technologies.
- Conduct special seminars, workshops, training for I4.0 technologies to develop a workforce that capable of meeting future challenges.
- Bring everyone together, from various areas and organizations in the public and private sectors, to make joint decisions regarding standards and I4.0.
- Encourage SMEs to adopt I4.0 technologies by providing special tax exemptions on equipment for smart manufacturing and smart products.
- Increasing the availability of financing earmarked to I4.0.
- Universities and vocational training colleges must revise their curriculum to incorporate courses relevant to I4.0 technologies so that the graduates are well equipped to meet the challenges in the industry. Universities must also take advantage of alternative learning platforms, like distant learning, online learning, open universities, and mobile apps for providing training on I4.0 technologies.

The companies should also invest in training and skill enhancement of existing employees and workforce due to their knowledge and experience of the current manufacturing processes.

This section of the thesis provided an insight into the potential of Turkey and the current situation of I4.0 in Turkey. This study is equally relevant for academicians as well as practitioners, as it delivers a critical analysis of recent research on Turkey's status in the context of I4.0, recognizes the government's policy initiatives, identifies the advantages and predicts the challenges, and proposes a way forward, and provides a foundation for further research.

This section on I4.0 in Turkey can be further extended in numerous directions. A future study is required to conduct empirical research to analyze the impact of I4.0 from economic, social, business, ergonomic perspectives, etc. Due to the limited literature on I4.0 in Turkey, it is strongly recommended that awareness, adoption, and readiness of I4.0 in Turkey must be further explored by the quantitative and qualitative studies based on improved MM. Detailed research is required to develop a novel MM by exploring; 1) the awareness and adoption of I4.0 technologies across the engineering enterprises, 2) potential benefits from this development, and 3) challenges and limitations faced while integrating the I4.0. Moreover, there is a need to broaden the scope to cover other manufacturing and associated industries, as I4.0 is a broad concept where engineering, manufacturing, distribution, service, and marketing are essentially linked in complex, real-time-optimized, value-added enterprise networks.

Chapter 3

RESEARCH METHODOLOGY

3.1 Research Strategy

The research strategy points out the way of answering the research question. In this regard, numerous strategies including ethnography, experiments, action research, case studies, narrative inquiry, surveys, archival research, and action research can be used for the research strategy. Each approach has unique characteristics, application context, and practicability according to the research objectives (Saunders, Lewis, & Thornhill, 2016). According to Saunders et al. (2016), each of these techniques has its own set of characteristics and implementation background. The best approach is determined by the researcher's preference and justification of this preference according to the study questions and objectives.

The overall methodology of the research includes Literature Surveys, Primary Data Acquisition through questionnaires, and Data Analysis. A quantitative survey-based approach will be adopted for this study.

The onion diagram illustrated by (Saunders et al., 2016) provides a better understanding of the thesis methodology. Each part of the union diagram represents a layer that dominates the techniques to capture and interpret the research data. Figure 3.1 illustrates the onion diagram.

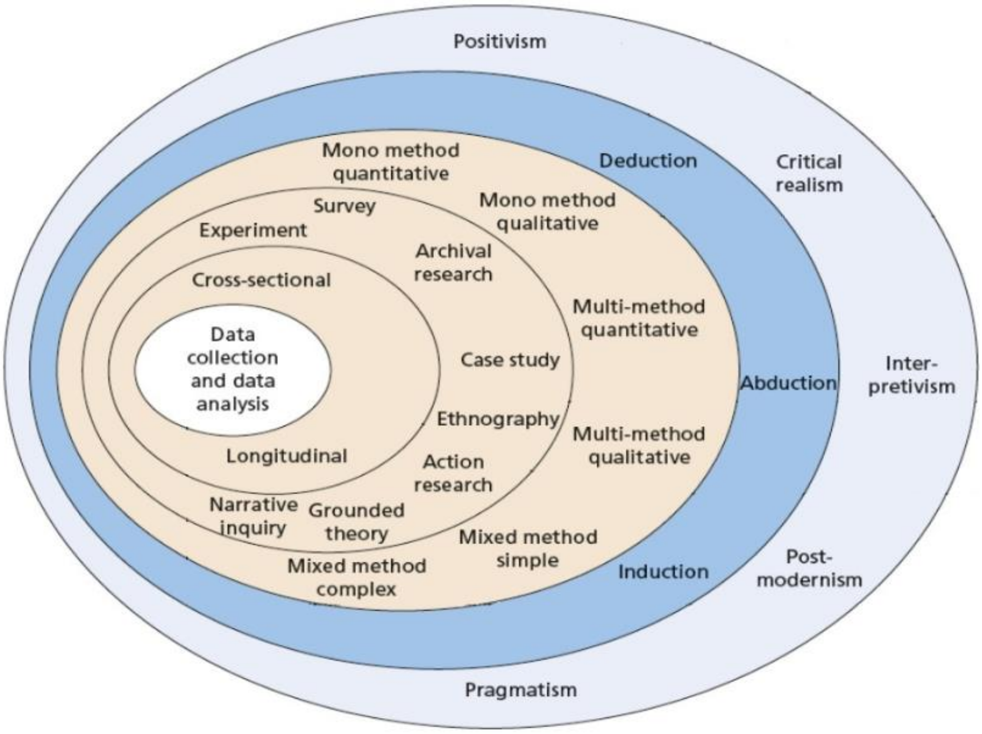


Figure 3.1: Research strategy in an onion diagram (Saunders et al., 2016).

3.2 Research Philosophy

Research philosophy is defined as the construction of assumptions, beliefs, and developed knowledge (Saunders et al., 2016). It is one of the essential parts of research as it presents how the researcher considers the research in its early stages. It also indicates the research methods and strategy towards the development of knowledge in a specific field. Following assumptions are provided to differentiate the research methodologies.

3.2.1 Ontology

Ontology is an assumption concerning the nature of reality by expressing how the research objectives have been considered by the researcher. An example of objectives in business and management; individuals, organization, and management. There are two different criteria to consider ontology that are objectivism and subjectivism. These two terms can be distinguished from each other. According to Saunders et al. (2016), Subjectivism maintains that social phenomena are formed by the expression, sensation, and subsequent activity of social actors, while objectivism is related to the occurrence of social entities outside of and regardless of social actors.

This thesis focuses on explaining a certain phenomenon within the organizations, and managers of the organizations are the main actors of the creation of the phenomenon through their perspectives. Therefore, the methodology of this thesis is based on the assumption of the subjectivism view.

3.2.2 Epistemology

Epistemology is an assumption that considers the knowledge of validity, acceptability and also concerns the way of knowledge transfer to others (Morgan, 1979). Knowledge can be obtained from various sources; numerical, textual, and visual data (Saunders et al., 2016).

This thesis aims to assess awareness, adoption of I4.0 in manufacturing enterprises by surveying managers. This thesis is also focused on exploring advantages, challenges, and willingness to invest in I4.0 technologies, and also provides a practical solution to overcome the challenges by proposing a roadmap that fulfills the maximum potential of these technologies in manufacturing enterprises. Therefore, a pragmatism assumption in terms of defining and communicating knowledge is adopted in this thesis. According to Saunders et al., 2016, knowledge and practical effect of ideas are valued to enable actions to be carried out effectively.

3.3 Research Approach

There are three research approaches; 1) inductive, 2) deductive and, 3) abductive. This thesis research suggests an inductive research approach, where it begins with the data collection or observation of a certain phenomenon to understand the problem under study. Data analysis is required to establish wider comprehension of the issue and to formulate the research hypothesis. The research approach is visualized in Figure 3.2.

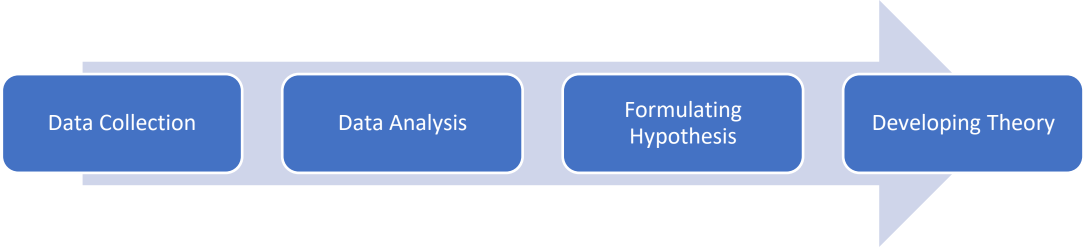


Figure 3.2: Inductive approach processes adapted from (Saunders et al., 2016).

In this thesis, the research methodology included literature surveys, primary data acquisition through questionnaires, and data analysis. A quantitative survey-based inductive approach was adopted. As this research was initiated to explore the adoption of I4.0 for smart manufacturing enterprises, the nature of this research was both exploratory and explanatory.

3.4 Research Methodology Selection

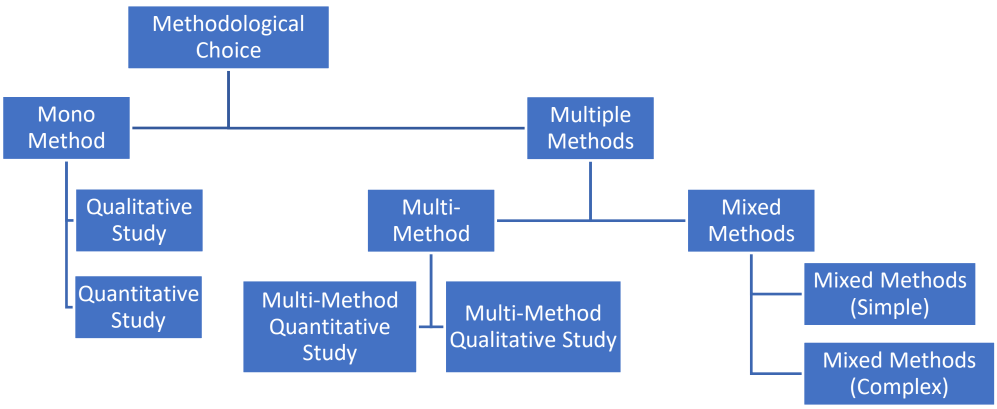


Figure 3.3: Methodological Choices. Adapted from (Saunders et al., 2016)

Methodological choices are presented in Figure 3.3. In quantitative research, data collection is usually performed through the survey which is easy to understand for the participants. Surveys are a cost-efficient method of data collection from various sources (Neuman, 2007; Shoemaker & McCombs, 2003). Required data can be collected quickly from the managers who don’t have time for other research methods. Researchers can have difficulties during the data collection in the survey method due to receiving a low response rate and non-representative sample size (Taylor-Powell & Hermann, 2000). For instance, Coatney and Poliak (2020) studied the outcomes of an exploratory review of the current research related to I4.0 in manufacturing systems using a survey. Horick (2020) conducted a survey-based study to evaluate and analyze I4.0 production networks. R. K. Yin (1994) presented three major applications for case studies. These applications are: (1) for the large evaluation, a case study should result from complementary and explanatory information (2) for primary evaluation method, the main case should be an evaluation of the initiative, and (3) for a dual-level evaluation arrangement in which a single evaluation contains one or more sub evaluations, a case study should play various roles to inform the program evaluation as a whole.

In this thesis, the case study approach is adopted to apply the proposed MM and F/W with TF for large automobile parts manufacturing enterprises. Our research methods are explained as a plan in Figure 3.4. The study started with a review of the literature based on I4.0 MMs and F/Ws. Existing MMs and F/Ws are reviewed to collect data about their MM levels/items and F/W layers. The findings from the literature led to the development of a new MM to fill the research gap, which was explained in the Introduction. To find inputs to evaluate the proposed MM, a survey was developed based on a quantitative study. From the respondents, the required data were collected via the survey. Collected data type and contribution to this research is illustrated in Table 3.1.

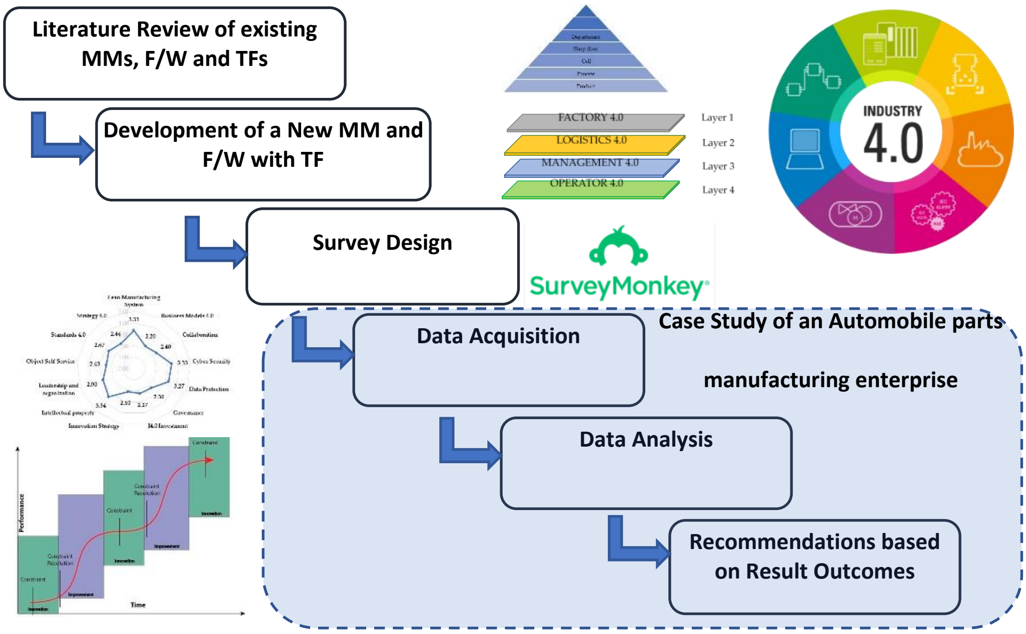


Figure 3.4: Research Methodology.

Table 3.1: Collected data and their contribution to this thesis.

Survey for Case Study		Survey for I4.0 Knowledge and Awareness	
Collected Data	**Contribution**	**Collected Data**	**Contribution**
General Information (Industrial sector/region/enterprise size)	To understand the type of industry is evaluated in this study	General Information (Industrial sector/region/enterprise size)	To understand the type of industry is evaluated in this study
What proportion of the manufacturing systems has I4.0 technology integration?	Data is used to evaluate factory 4.0 level of the maturity	Which of the following systems and technologies are used or intend to use in near future?	To understand the I4.0 knowledge and use of I4.0 technologies in their organizations
What proportion of the logistic systems has I4.0 technology integration?	Data is used to evaluate logistics 4.0 level of the maturity	Which of the following benefits and challenges are seen or expected in your organization from adopting I4.0?	To obtain most highlighted benefits/challenges from I4.0 adoption
Which of the business model is used in the organization and what is the innovation strategy?	Data is used to evaluate management 4.0 level of the maturity	Which of the following I4.0 standards you are aware of? or used in your organization?	To understand the awareness and knowledge of I4.0 standards
To what extend the organization support operators and to what extend the organization focus on workload managements systems?	Data is used to evaluate operator 4.0 level of the maturity	How COVID-19 has affected the adoption/transition to I4.0?	To understand how COVID-19 is affected the I4.0 transition

The questionnaire was designed based on the proposed MM and F/W. The participants comprised experts from various fields and management levels working for automotive parts manufacturing enterprise. The questionnaire was designed in the Survey Monkey platform as an online survey. Ethical approval was obtained from the Eastern Mediterranean University (EMU) Ethics Committee and their valuable suggestions and comments were considered before disseminating the survey. The participants were informed about the scope of the research and their identities were kept anonymous. Data analysis was performed to determine the level of awareness and maturity in the fourth industrial revolution. Based on the collected data, the Gompertz growth model and a logistic growth model were applied to forecast the technological expectations in the coming years. Moreover, I4.0 knowledge/awareness, I4.0 advantages, challenges, and willingness to invest are identified by surveying Turkish manufacturers, and also a detailed discussion on advantages and challenges foreseen in the transition to in the context of Turkey is presented based on the survey.

3.4.1 Literature Awareness

Firstly, a critical study was performed to understand the literature in English sources. Later on, significant effort was spent to gather more information about I4.0 in Turkish sources. Literature awareness was led to find out the literature gap. The literature gap is explained in Chapter 1 and also literature findings are explained in Chapter 2.

3.4.2 Maturity Model Proposal

This thesis aims to investigate the I4.0 adoption by exploring; the awareness and adoption of these technologies across the engineering businesses and, potential benefits from this development, and major barriers and constraints faced while adopting to I4.0. Therefore, I4.0 technologies are evaluated based on specific subheadings called dimensions in the MM. This approach provides to investigate awareness, knowledge, readiness, willingness to invest, challenges, and benefits of I4.0 in Turkey. Proposed MM is presented in Chapter 4.

3.4.3 Development of A Survey and Data Analysis

A survey-based questionnaire is prepared in Microsoft Word file and Survey Monkey. In this way, required input collection is performed for the proposed MM. Each question in the survey was carefully chosen to gather appropriate data for MM. Findings are visualized by using radar charts to clarify awareness, knowledge, readiness, willingness to invest, challenges, and benefits of I4.0 in Turkey. Survey and data analysis are explained in Chapter 5.

3.4.4 Technology Forecasting

In this thesis, an array of methods is used to predict the future performance of I4.0 technologies. TF is carried out to provide an overall perspective to organizations aiming toward readiness of industrial revolution and to anticipate the direction and rate of I4.0 integration. TF evaluation and details are presented in Chapter 4.

3.5 Scope of The Survey

The participants are consisting of experts from the micro, small, medium, and large enterprises across various industries including automotive, aerospace, agriculture, food & beverage, transport, etc. The questionnaire is designed to satisfy objectives of this thesis. Likert Scale was implemented for the questionnaire.

The ethical approval is acquired (Date: 30.10.2020, issue: 2020/4, no: ETK00-2020-0220) from the EMU Ethics Committee and their valuable suggestions and comments were taken into consideration before disseminating the survey. The participants were informed that their identity will be kept anonymous and that the research information would not be available in raw data form to anyone other than the researchers.

Data were gathered from the questionnaire form filled by the respondents. The questionnaire was being accessible in Survey Monkey via the internet. Gathered data is analyzed by using M.S. Office.

3.6 Survey Design

Two different survey questionnaires are prepared for this thesis. First questionnaire to provide the required data for the readiness F/W model. The survey questionnaire is used to explore the following aspects:

- Structural attributes of the companies
- General questions on I4.0
- The degree to which companies satisfy the dimensions of I4.0
- Motivators and obstacles on the road to I4.0

The survey structure is divided into four parts. In the first part, respondents are asked to sign off a consent form to ensure they will be part of this research. In the second part, respondents are asked to deliver information about the work experience, expertise, and general structure of their companies. Provided information in this part is used to ensure that the questionnaire is representative and enable projections. The third part includes general questions about the I4.0 and to what extend I4.0 technologies are used in the company. This part is called the heart of the survey and includes a self-assessment of the I4.0 adoption for the company. Self-assessment indicators were used to explain MM dimensions and to measure the extent to which these indicators were present. In the fourth part, respondents are asked to provide a source of motivation and major obstacles for implementing I4.0. First questionnaire details are provided in Figure 3.5.

Second questionnaire is prepared for exploring; 1) the awareness and knowledge of I4.0 technologies across the engineering enterprises, 2) potential benefits from this development, and 3) challenges and limitations faced while integrating the I4.0. Second questionnaire details are provided in Figure 3.5. The survey flowchart is shown in Figure 3.6.

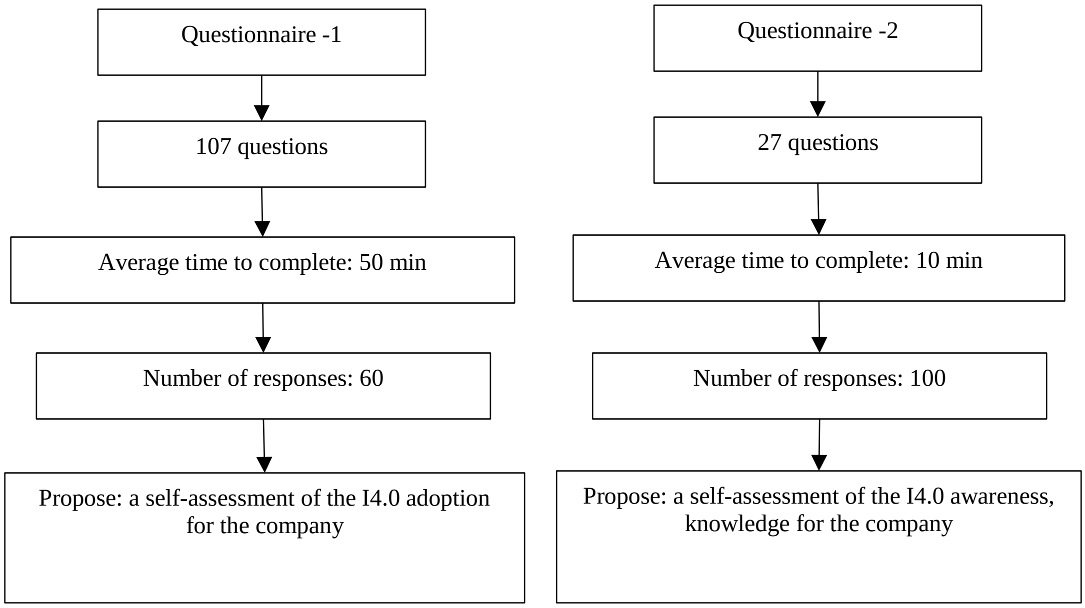


Figure 3.5: Survey questionnaires.

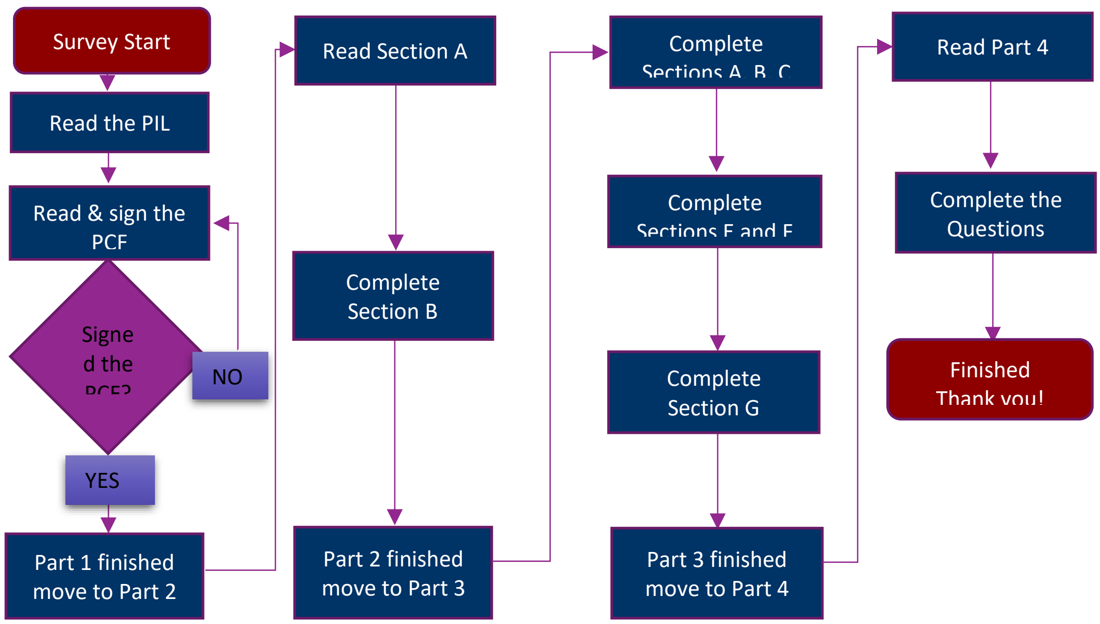


Figure 3.6: Survey flowchart explains the process for completing the survey.

The survey mainly comprises four parts and an appendix. They are:

- Part 1: Participant Consent Form (PCF) (Mandatory).
- Part 2: Personal Information (Section A: Optional, Section B: Mandatory)
- Part 3: Questionnaire.
- Part 4: General Questions.
- Appendix: Definition of Key Terms.

3.6.1 Survey Evaluation Concept

Survey results were used to evaluate the I4.0 adoption of the enterprise based on a weighted average of the company and the lowest score of the company in any single I4.0 concept within the associated MM dimension. The average score in four dimensions was merged with the weighted gap to assess the overall readiness score of the company. The importance of each I4.0 concept has been asked to participants to determine the formula for weighting the dimension scores. The dimensions are defined:

- Factory 4.0

- Logistics 4.0
- Operator 4.0
- Management 4.0

3.7 Data Analysis

The proposed MM and F/W integrated with TF provide insight into the current situation and growth of the smart manufacturing enterprise regarding I4.0 adoption, helps with explicitly identifying the gap areas, and provides a foundation for policy decisions for I4.0 integration to maximize the potential of I4.0. Survey method were applied to collect data to evaluate level of maturity of the organization. Data collection and evaluation is shown in Table 3.2.

Table 3.2: Data collection and evaluation procedure.

No	I. Level Dimension	II. Level Dimension	Firm I4.0 score	Theoretical Max Level	Firm Target Level	Importance for your firm [1-5]	Firm Gap to target	Weight Gap
1	Factory 4.0	Automation	3.47	5.00	3.97	4.37	0.50	0.44
2	Factory 4.0	Autonomous workplace	3.33	5.00	3.70	4.03	0.37	0.30
3	Factory 4.0	Autonomous workplace	2.53	5.00	2.87	3.30	0.33	0.22
4	Factory 4.0	Autonomous workplace	2.77	5.00	3.07	3.70	0.30	0.22
5	Factory 4.0	Big Data Analytics	2.43	5.00	2.83	3.57	0.40	0.29

Collected data is evaluated based on the mathematical model proposed by (Schumacher et al., 2016). After data collected, firm gap to target and weighted gap are calculated based on Equation (1) and Equation (2) in Chapter 4. Maturity level of each MM dimension is calculated and Overall company maturity level is then calculated based on Equation (3) presented in Chapter 4. The weighting strategy of survey questions is not applied in this thesis. However, importance of each question is evaluated based on the responses given by the participants.

Gathered data from the survey were used to identify the I4.0 readiness, I4.0 advantages, challenges and willingness to invest by surveying manufacturers, and also (4) have a detailed discussion on advantages and challenges foreseen in the I4.0 transition. The thesis results are presented in spider charts.

Chapter 4

DEVELOPMENT OF A NEW MATURITY MODEL AND FRAMEWORK INTEGRATED WITH TECHNOLOGY FORECASTING

4.1 Proposed Maturity Model

4.1.1 Dimension Design

The first step after thoroughly exploring the literature was to conduct a study with select leading companies from various industries that already had experience or had the intent to invest in I4.0 technologies. In this study, I4.0 success-related indicators are systematically identified and an evaluation diagram is presented in Figure 4.1.

Based on the literature, the next step was to explore the literature to identify an appropriate MM. However, the existing MMs include little information on mechanism, structure, and evaluation technique creation. The operator role in I4.0 is insufficiently mentioned in existing MMs because the design of a readiness MM requires the evaluation of the readiness and maturity of an enterprise. A novel I4.0 MM was constructed placing heavy emphasis on operational dimensions, seeking to expand current models and resources. The concept of the proposed MM was designed to evaluate I4.0 maturity for real-world manufacturing enterprises, and this generic MM can be adopted to any size of an enterprise. The model details, structure, and assessment procedure ensure transparency for the enterprises.

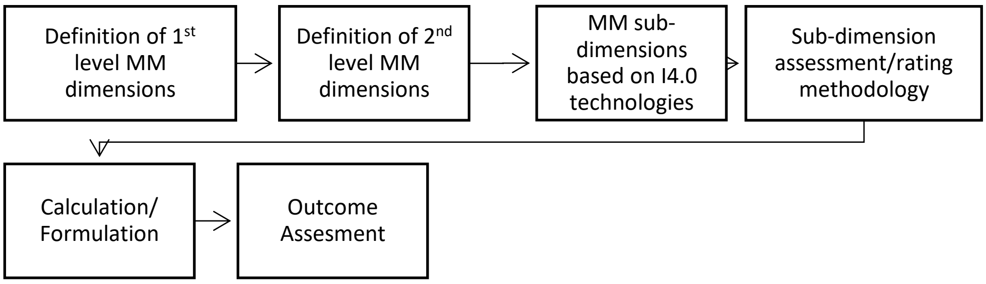


Figure 4.1: MM assessment flow diagram.

Sub-dimensions, which delineate the thematic focus of the assessment model and cover a wide range of subject matter inquiries about introducing I4.0 technologies (Barbato, Ceselli, & Premoli, 2019). Each dimension of a MM is subdivided into more detailed aspects with a scoring scheme, and each aspect is measured and aggregated at a dimensional level (Weber et al., 2017). The proposed MM was subjected to the MM assessment flow diagram presented in Figure 4.1, which comprises four levels of I4.0 readiness. They have explicit statements of what needs to be achieved to reach that particular level of readiness for each sub-dimension (The University of Warwick (WMG), 2017). The proposed MM considers 4 core dimensions, 32 second-level dimensions, and 55 sub-dimensions. The core dimensions are listed in Table 4.1.

Table 4.1: Proposed MM dimensions and their scope.

No	MM Dimension	Description
1	Factory 4.0	A concept that refers to a modern factory paradigm that has arisen as a result of the fourth industrial revolution. Mechanization, industrialization, and automation are the predecessors of the first three major developmental processes that are known as revolutions.
2	Logistics 4.0	The use of digital technologies in the supply chain is referred to as Logistics 4.0. The different facets of end-to-end logistics and supply chain management are discussed by Logistics 4.0.
3	Operator 4.0	The primary enabling factor of the resultant Operator 4.0 paradigm focuses on advanced sensors and actuator systems, as well as connectivity solutions.
4	Management 4.0	Applies to I4.0 management paradigms such as the aging population, resource-effective and clean urban manufacturing, mass customization, growing demand heterogeneity, shorter product life cycle, competitive supply chain, unpredictable economies, and cost-containment pressure.

Table 4.2 provides a thorough breakdown of the related sub-dimensions of the corresponding maturity thresholds for each dimension. The MM was created to illustrate the company's long-term priorities and the differences in the present and long-term goals. The assessment was developed to be completed as a group, as well as individually. It acts as a foundation for furthering the discussion to ensure that companies are taking advantage of the possibilities provided by the I4.0 era.

Table 4.2: Proposed MM dimensions and sub-dimensions.

1st-Level Dimensions	2nd-Level Dimensions	Subdimensions / I4.0 concept
Factory 4.0	Technology integration	Agile manufacturing system
		Automated manufacturing and assembly
		Continuous and uninterrupted material flow models
		Plug-in produce
	Autonomous workplace	Self-adapting manufacturing systems
		Autonomous robotics
	Data-driven services	Integrated and digital real-time monitoring systems
		Remote monitoring of products
	Robotics and automation	Smart assistance systems
	Digital modeling	Digital twin
		Computer-aided manufacturing (CAM)
		Additive manufacturing (3D printing)
		Augmented reality
	Big Data	Big data analytics
		Traceability (MES) integration
		Cloud computing
	Machine Learning	Artificial intelligence
	IT-supported business	Industrial internet of things (IIoT)
	Smart Products	Identification and tracking technology
		Customized products
		Digital product-service systems
	Product Design and Development	Product lifecycle management
	Communication and Connectivity	Digital and connected workstations
		Internet of things
		Cyber-physical systems
	Operations	Self-adapting manufacturing systems
Logistics 4.0	Transparency	Automated Material Replenishment (E-Kanban)
	Customers	End-to-end visibility
	Inventory control	Wireless communication
	Supply chain	Vertical and horizontal system integration
		Sustainable supply chain design
		Collaboration network models
	Real-time tracking	Smart sensors
	Warehouse and Storage	Automated storage systems
	Automated scheduling	Smart assistance systems

Operator 4.0	Collaboration	Cultural transformation
	Human resources 4.0	Training 4.0
	Governance	Operator role
	Operator ergonomics	Automated material handling systems
		Collaborative robots
Management 4.0	Leadership and organization	Decentralization
	Scheduling and maintenance	Predictive maintenance
		Tele-maintenance
		Object self-service
	Investments	Real-time process control systems
	Finance	Material requirements planning (MRP)
		Manufacturing resource planning
		Servitization and sharing economy
	Data security	Cyber security
	Intellectual property	Copyrights and patents
	Business models 4.0	Digital lock-in
		Freemium
	Standards 4.0	CPS standards
	Innovation strategy	Open innovation
		Strategy 4.0

Factory 4.0

A smart factory is an intelligent, interconnected factory. Completion of I4.0 integration in traditional production allows for distributed and fully automated operations, auto-guided systems through production, and real-time monitoring of product operations. These technologies are required in the smart factory environment. Production, supply chain, and logistics are extensively organized without requiring human assistance. The use of cyber-physical systems (CPSs) provides interconnection between virtual environments and physical environments in which I4.0 technologies are effectively used to provide or gather clean data for digital modeling. As such, real-time cross-enterprise collaboration between IT, production, and operators can be provided. Consequently, the accumulated large amounts of data can be used for decision-making models (Wan, Hong, Pang, Jayaraman, & Shen, 2019).

Sub-Dimensions

1) **Technology Integration:** Agile Manufacturing Systems, Automated Manufacturing & Assembly, Continuous and uninterrupted material flow models, Plug in Produce.
2) **Autonomous workplace:** Self-Adapting Manufacturing Systems, Autonomous Robotics.
3) **Data-driven services:** Integrated and Digital Real-Time Monitoring Systems, Remote Monitoring of Products.
4) **Robotics and Automation:** Smart Assistance Systems
5) **Digital Modelling:** Digital Twin, Computer-Aided Manufacturing (CAM), Additive Manufacturing (3D Printing), Augmented Reality.
6) **Big Data:** Big Data Analytics, Traceability (MES) Integration, Cloud Computing.
7) **Machine Learning:** Artificial Intelligence.
8) **IT Supported Business:** Industrial Internet of Things (IIoT).
9) **Smart Products:** Identification and Tracking Technology, Customized Products, Digital Product-Service Systems.
10) **Product Design and Development:** Product Lifecycle Management.
11) **Communication and Connectivity:** Digital and Connected Workstations, Internet of Things, Cyber-Physical Systems.
12) **Operations:** Self-Adapting Manufacturing Systems

Logistics 4.0

Barreto et al. Barreto, Amaral, and Pereira (2017) described Logistics 4.0 using five characteristics: (1) real-time big data analytics (BDA), for instance, optimized routing; (2) autonomous robots with tracking (3) decision-making or decision support systems; (4) real-time information exchange; and (5) the use of complex systems supported by CPSs. Winkelhaus and Grosse (2019) described Logistics 4.0 as the replacement of existing hardware-oriented logistics with software-oriented logistics. To standardize the definition of Logistics 4.0, three aspects are used:

- Change in the production paradigm to mass customization in logistics (Kuehnle, 2007);
- Replacement of existing logistics operations with the new digital technologies, e.g., instance, CPS, IoT, etc.;
- Consideration of human factors and product customization toward changing environments, e.g., employees, customers, and stakeholders.

Sub-Dimensions:

1) **Transparency:** E-Kanban.
2) **Customers:** End-to-end visibility.
3) **Inventory Control:** Wireless Communication.
4) **Supply Chain:** Vertical & Horizontal System Integration, Sustainable Supply Chain Design, Collaboration Network Models.
5) **Real-Time Tracking:** Smart Sensors.
6) **Warehouse and Storage:** Automated Storage Systems.
7) **Automated Scheduling:** Smart Assistance Systems.

Operator 4.0

Interactions between operators and machines are crucial in digital transformation. To provide an intelligent workforce that substantially impacts the nature of work, workers are required to be integrated into I4.0 technologies (Ruppert, Jaskó, Holczinger, & Abonyi, 2018). Integration can be easier depending on the operator's skills, education level, cultural background, physical ergonomics, and cognitive ergonomics (Fallaha et al., 2020). Otherwise, integration may be challenging. Therefore, the Operator 4.0 concept was created to understand the operator role and related technologies based on human–cyber-physical systems (H-CPSs) to simplify cooperation between machines and humans (Romero et al., 2016; Ruppert et al., 2018).

Sub-Dimensions:

1) **Collaboration:** Cultural Transformation.
2) **Human Resource 4.0:** Training 4.0.
3) **Governance:** Operator Role.
4) **Operator Ergonomics:** Automated Material Handling Systems, Collaborative Robots.

Management 4.0

The Management 4.0 concept covers the high investment cost and risks associated with the I4.0 technologies (e.g., predictive maintenance, digital twins, etc.). The necessity of new business models including I4.0 technologies was considered (Ruppert et al., 2018). To successfully implement I4.0, investments in new technologies are required. With new technologies, investment costs and service costs can pose challenges. It is conceivable that the client may fail to share the investment costs (Ruppert et al., 2018). These packages can be risky for the organization but also provide the possibility of taking complete advantage of technical competence when designing the system based on the optimal performance of the operation and maintenance (Çınar et al., 2020). Data processing is used in services and represents a technology-driven market growth approach (Kans & Ingwald, 2016). Willingness to invest in I4.0 is another critical point for I4.0 integration. Therefore, top management's perspective, technology integration challenges, and benefits need to be considered periodically in strategy meetings.

Sub-Dimensions:

1) **Leadership and Organization:** Decentralization
2) **Scheduling and maintenance:** Predictive Maintenance, Tele-Maintenance, Object Self Service.
3) **Investments:** Real-Time Process Control Systems.
4) **Finance:** Material Requirements Planning (MRP), Manufacturing Resource Planning, Servitization, and Sharing Economy.
5) **Data security:** Cyber Security.
6) **Intellectual Property:** Copyrights and Patents.
7) **Business Models 4.0:** Digital Lock-in, Freemium.
8) **Standards 4.0:** CPS Standards.
9) **Innovation Strategy:** Open Innovation, Strategy 4.0.

4.1.2 Proposed MM Level Design

The assessment was designed around five readiness levels as explained in Table 4.3 using explicit statements about what needs to be done to achieve each sub-dimension's degree of preparation. Level 2 is intermediate level of proposed MM, where the company takes the first steps towards I4.0 adoption. Therefore, level 2 is a threshold level of each MM dimension for an early adoption of I4.0.

Table 4.3: I4.0 Levels and their descriptions.

Levels	Experience	Description
Level 0	Outsider	Companies have not done anything to deal with I4.0.
Level 1	Beginner	Companies have I4.0-based plans and pilot applications
Level 2	Intermediate	Companies have already taken the first step in I4.0 integration
Level 3	Experienced	Companies use I4.0 technologies in particular areas but I4.0 is not yet extended to the whole company
Level 4	Top Performer	Leading companies that are already well on the way to I4.0 integration

Level 0: Outsider

Level 0 is the outsider maturity level indicates that the company is not involved in I4.0 and production processes are not supported with the I4.0 technologies. The equipment infrastructure of the company does not satisfy the I4.0 requirements. Therefore, the company at this level is not within the scope of I4.0.

Level 1: Beginner

Level 1 is beginner maturity level indicates that the company has partially been involved in I4.0 technologies through pilot applications and investments in a single area. Production processes are partially involved I4.0 technologies. The equipment infrastructure of the company is not capable of satisfying I4.0 requirements as well as communication requirements. However, IT systems, system integrations, information sharing are limited to a few areas at this level. Cybersecurity and IT-based functionalities are still in the implementation phase or planned for implementation—significant effort is required to expand I4.0 integration at this level.

Level 2: Intermediate

Level 2 is the intermediate maturity level that the company has an I4.0 strategy. Investments related to I4.0 technology integration in several areas are planned, and pilot applications have already been performed through department-oriented innovation management. Limited I4.0 technologies are used and linked with the interfaces. Manufacturing processes can automatically provide data, and clean data can support decision-making systems in selected areas. Equipment infrastructures allow future expansion of technology integration with a retrofit. IT-based add-on functionalities are used for product production at this level. Cloud-based systems, data-driven services are used in the company, but they are not shared with the customer. The company has limited end-to-end visibility. However, significant efforts have been made to expand I4.0 technology integration at this level.

Level 3: Experienced

Level 3 is the experienced maturity level that the company has an I4.0 strategy and periodically reviews the current status with appropriate indicators. Almost all areas of the company have invested in I4.0 technologies through interdepartmental innovation management. Manufacturing processes are supported by IT systems that allow a large amount of data collection to optimize process optimization. Equipment infrastructure satisfies future integration requirements towards further expansion. Internal information is shared with the customers and business partners that have integrated mainly I4.0 technologies. Cloud systems and data-driven services are utilized in the relevant areas. However, automated guiding workpieces, self-adapting manufacturing processes, and self-reaching processes are not autonomously provided at this level. Products have IT-based add-on functionalities and allow a large amount of data collection, shared with the customer and suppliers. Therefore, the company has end-to-end visibility at this level. The company has already integrated I4.0 technologies almost in all relevant areas, but the company requires an additional effort for fully I4.0 integration.

Level 4: Top Performer

Level 4 is the top performer maturity level that the company has fully integrated I4.0 and periodically reviews future projects. The top management team adopts Enterprise-wide innovation management throughout the company. IT systems are widely used in manufacturing processes to collect data and use it for decision support systems with the help of cloud systems and data-driven services. All the requirements for I4.0 and system communications are established by equipment infrastructure at this level. Internal information is shared with the customers as well as business partners that have largely integrated I4.0 technologies. Therefore, end-to-end visibility is provided. Exclusive cyber security systems, IT architectures are adopted by the company. Cloud systems and data-driven services are utilized in all areas. Autonomously guided workpieces, self-adapting manufacturing processes, and self-reaching processes are autonomously provided in limited or all areas at this level. Products have IT-based add-on functionalities to provide a large amount of data collection shared with the customers and suppliers. Collected data is also used for sale support, predictive maintenance, product development. The company is capable to provide in-house expertise in core areas and able to expand with I4.0.

4.1.3 MM Evaluation

The assessment was designed around five readiness levels using explicit statements about what needs to be done to achieve each sub-dimension's degree of preparation. A three-step procedure is utilized to evaluate and represent the maturity level of the company under study. The three-step procedure is shown in Figure 4.2.

Figure 4.2: Three-step procedure to measure I4.0 maturity.

After thoroughly exploring the literature, we identified existing MMs, F/Ws that already intend to apply in Industry. In this study, I4.0-success-related indicators were systematically identified. The completion of the systematic representation of the theoretical evaluation model allowed us to delineate the estimation process. In particular, the evaluation method can be divided into five components: target score, the importance of the company, the gap to the target, level of the MM, and the weighted gap.

The enterprise's I4.0 score is a quantitative rating given by the enterprise's delegate. The respondent attempts to estimate the degree of I4.0 regarding a specific definition. The company score in 2 years is a quantitative rating that represents the I4.0 standard in comparison with a definition that the enterprise delegate indicated would be suitable for their sector. The importance score is a subjective value that encapsulates the degree of significance of the discussed I4.0 definition. The company's gap to the target describes the known shortcomings that must be resolved to reach a competitive position. Subtraction can be used to calculate the size of the distance, as illustrated in Equation (1) (Unterhofer, 2018). The final procedural step of the MM evaluation method is the weighted gap. Equation (2) is used to calculate the weighted gap (Unterhofer, 2018).

$$\text{Company's gap to target} = \text{Company I4.0 score in 2 years} - \text{Company's I4.0 score} \quad (1)$$

$$\text{Weighted gap} = \frac{\text{Company's gap to target} \times \text{Importance of the company}}{\text{Level of the MM}} \quad (2)$$

The maturity level of each dimension is then calculated by taking the weighted average of all maturity items within their relevant dimension. For each object, the weighting factor equals the average significance ranking of all respondents. The maturity level is determined by applying Equation (3) (Schumacher et al., 2016), where M stands for maturity, D represents dimension, I is the item, G is the weighting factor, and n is the number of maturity items in the equation.

$$M_D = \frac{\sum_{i=0}^{n} M_{DIi} * g_{DIi}}{\sum_{i=1}^{n} g_{DIi}} \quad (3)$$

4.2 Framework Development

4.2.1 Framework Layers

The approach of this thesis is to investigate awareness, knowledge, readiness, willingness to invest, challenges, and benefits of the industry. Proposed MM should speak with the proposed F/W to provide a reliable investigation for I4.0. In this regard, F/W layers are developed from MM dimensions. F/W layers are shown in Figure 4.3.

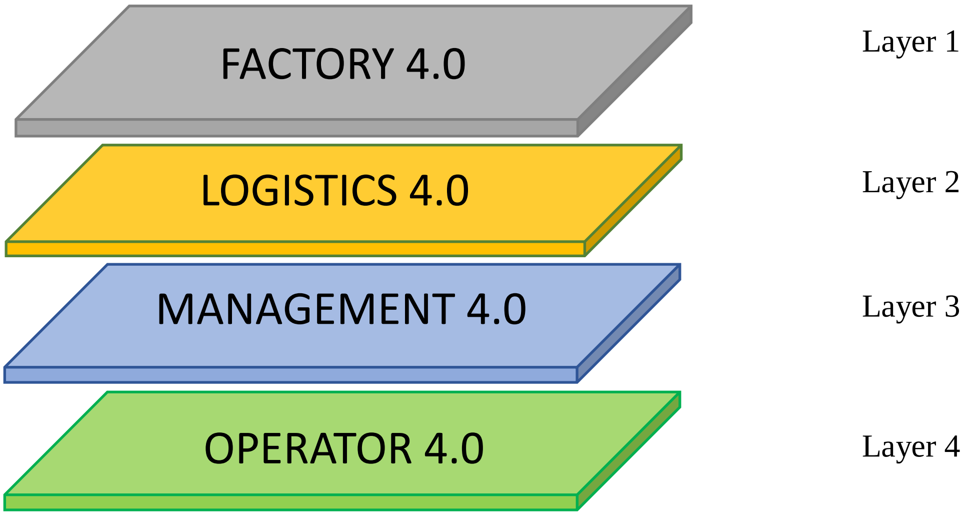


Figure 4.3: Framework layers.

4.2.2 Framework Life Cycle Value Streams

Clear accountability and integrated support structures require customer-focused value streams and help to maximize customer and shareowner value. It incorporates a process for increasing the ratio of value to non-value in the overall life cycle of customer deliverable products. It also ensures the value stream meets or exceeds customer requirements—the life cycle value stream of the F/W is designed in 5 flows and each flow illustrated in Figure 4.4.

1. Flow 1: Refers to initial requirements to obtain a new product for the organization.
2. Flow 2: Refers to theoretical strategy and capability development of the new product for the organization.
3. Flow 3: Continuation of the existing business in parallel to the new product.
4. Flow 4: Refers to the development of production processes in manufacturing.
5. Flow5: Refers to provide goods and services after obtaining the new product.
6. Continuous Improvement: Refers to monitor and continuously improve the obtained product.

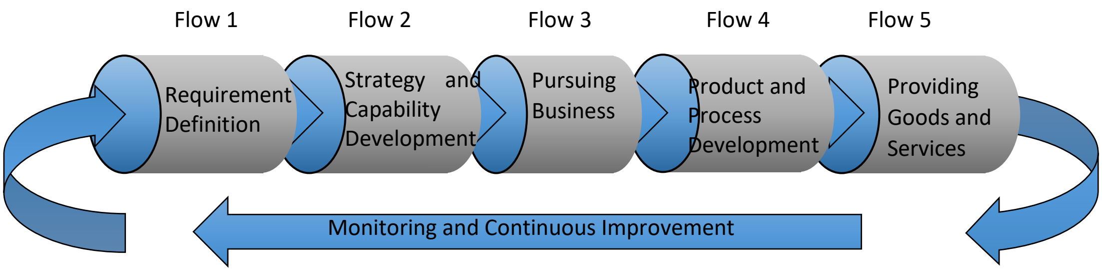


Figure 4.4: Framework life cycle value stream.

4.2.3 Framework Hierarchy Levels

As a generalization, the F/W hierarchy is divided into 7 parts and associated with specific levels. Broadly, hierarchy levels are designed to understand that at what level I4.0 key technologies integrated into the organization. Hierarchy levels are presented in Figure 4.5. I4.0 adoption starts with a very specific part that is the product and goes to the general that is the smart plant. The smart plant provides that I4.0 adopted in the whole company including suppliers, production, logistics, and customers.

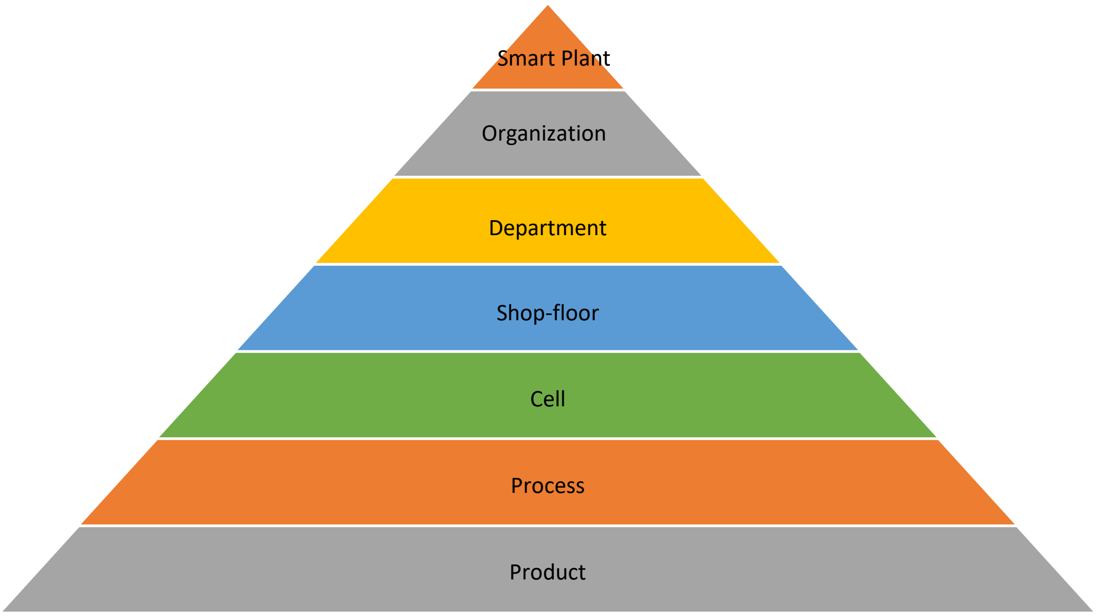


Figure 4.5: Framework hierarchy levels.

4.2.4 Framework Structure

F/W structure is a method to visualize the maturity level of the layers as well as to provide the organization's overall maturity level. Also, F/W provides a roadmap to organizations that include specific requirements to fully adopt I4.0. The F/W structure template is presented in Figure 4.6.

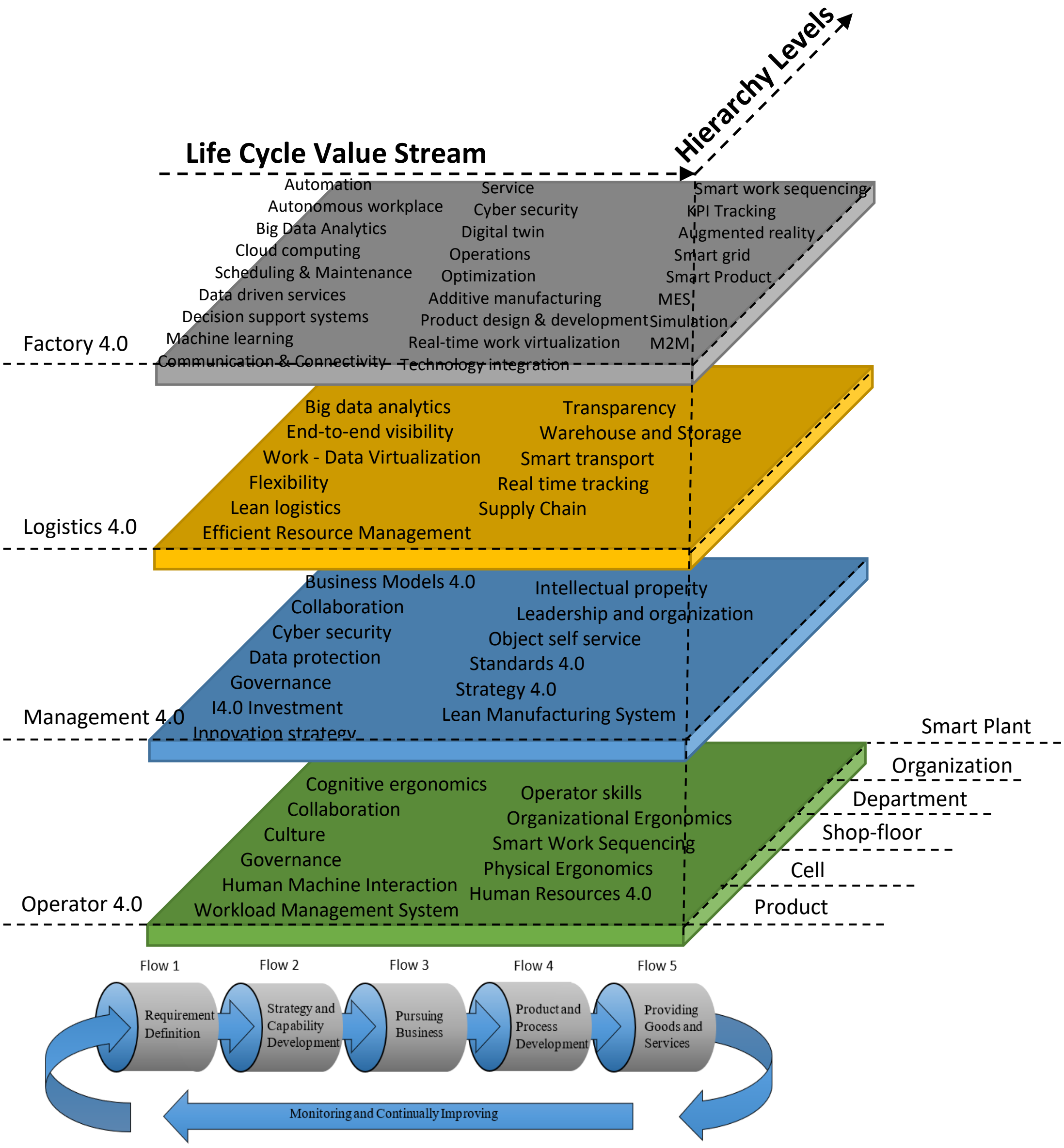


Figure 4.6: Framework structure template.

4.3 Technology Forecasting

4.3.1 Reasons for Technology Forecasting

TF has been emerging for several years, and it is still developing since many new technological developments increase the demands of forecasting tools. The Most Common Reasons for TF are studied by (Porter, 1999) and presented in Table 4.4.

Table 4.4: Most Common Reasons for Technological Forecasting (Porter, 1999).

● Guidance of resource allocation
● Identification of market opportunities or threats
● Guidance of staff, facilities, or capital planning
● Development of strategies or policies
● Assistance with R&D management
● Evaluation of new products
● Maximize gain or minimize loss due to internal or external elements of the organization

Modern technology forecasters use various methods to predict a technology's future performance, including methods based on complex mathematics such as time-series analysis, stochastic methods, and simulation. These methods often rely on the assumption that past behavior will continue. These forecasts complement techniques based on expert opinion and panels by providing extrapolative results that are quantified and reproducible. Although forecasters attempt to make accurate forecasts, insights gained from the technological forecasting process can provide value whether the predictions are accurate or inaccurate (Ayres & Kneese, 1969).

In summary, modern forecasters have an array of flexible tools that may be used for several business purposes. Although the forecasts may not always be accurate, the insight they help to generate can be valuable and have a significant impact on their organizations. This particular area of research is significant in its ability to help organizations avoid costly mistakes.

4.3.2 Technology Forecasting Methods

TF can be used for both quantitative or qualitative studies. These studies offer an auxiliary role to managers, and they are required to choose the use of quantitative or qualitative methods. In general, the life cycle of a product or a service displays a bell-shaped curve, and this curve consists of five parts: innovators, tornado, main street, decline, and obsolescence. Similarly, the technology adoption life cycle is divided into five parts: innovators, early majority, late majority, and laggards (P. T. Meade & Rabelo, 2004). Hence, the growth of adopters in new products or services can look like a sigmoid curve. Some TF approaches can be a tool to fit and forecast a trend, e.g., Fisher-Pry and Gompertz. However, many existing models are adapted, or new models are developed in the literature (Carrillo & González, 2002). These approaches can fit data sets fine in some specific products or services, such as the rate of mobile phone adoption, and it represented the trend of a new product or a service.

Frank, Seeberger, and O'reilly (2004) applied the modified logistic model to forecast wireless communications, and Vanston (2002) implemented the Fisher-Pry and Gompertz models to forecast the use of residual broadbands. TF often utilizes the “S” curve to direct the phases at which technologies grow from initial adoption to development and then maturity (S. Chen, 2005). To understanding technological trends and have insights on the adoption of I4.0 technologies, TF models are utilized to generate forecasts that help in developing a better understanding of how technologies develop in markets. This, in turn, assists decision-makers and company managers to understand the potential of certain technologies for their businesses. According to (S. Chen, 2005), TF can be classified into five families: monitoring, expert opinion, trend extrapolation, modeling, and scenarios. Table 4.5 elaborates the advantages, limitations, and usages of each approach. A suitable technology growth forecasting model should be adopted to predict the growth of I4.0 technologies.

Table 4.5: Comparison of Technological Forecasting Methods (S. Chen, 2005).

	Strengths	**Weaknesses**	**Uses**
Monitoring	Providing large useful information.	Information overload happened without selections.	To provide useful information for structuring a forecast.
Expert Opinion	Tapping high-quality models internalized by experts	Identifying experts is difficult, and some extraneous factors will affect experts.	To forecast when experts in this field exist and where data are lacking.
Trend Analysis	A substantial and data-based forecast of quantifiable parameters.	It requires good and enough useful data, and it did not explicitly address the causal mechanisms.	To project quantifiable parameters and analyze adoption and substitutions of technologies.
Modeling	Simplify the future behavior of complex systems. The building process provides good insight into complex system behavior.	Models that are not heavily data-based may be misleading.	To reduce the complex systems to manageable representations.
Scenarios	It can portrait the possible futures explicitly and incorporate qualitative information and quantitative information to others.	It may be more fantasy than forecast unless the forecasters maintain a firm basis in reality.	To integrate quantitative and qualitative information and to integrate forecasts from various sources. To provide a forecast when data are too weak to use other methods.

Several methods can be used to forecast the future performance of technology, such as simulation, stochastic methods, and time-series analysis (Porter, 1999). These approaches are based on the premise that prior behaviors will persist and thus quantified, reproducible, and extrapolative results can be obtained (Porter, 1999). As the results are obtained from complimentary techniques based on expert opinion, technological forecasting insights can provide value, although the predictions are inaccurate (Ayres & Kneese, 1969). Although predictions are not necessarily reliable, the knowledge can be incredibly helpful and have a huge effect on organizations when creating a road map toward I4.0 integration.

Various TF studies have been performed to examine a broad variety of developments, including Radio Frequency Identification (RFID), programming languages, optical storage, fuel cells, food protection, 3D television, operating systems, and so on (Akinlabi, Solyali, Asmael, & Zeeshan, 2020). The growth pattern is used to investigate the innovation process and the features of the market (H.-j. Lee, Lee, & Yoon, 2011). The S curve provides an understanding of how technology evolves without historical data over time, but it is important to follow the disruptive technology's advancement as it travels down the S curve of sustaining technology (Adamuthe & Thampi, 2019).

In this study, trend analysis based on expert opinion was used to conduct TF to provide an overall perspective to organizations aiming toward the readiness of the industrial revolution and to anticipate the direction and rate of I4.0 integration. The S-curve evaluation is shown in Figure 4.7.

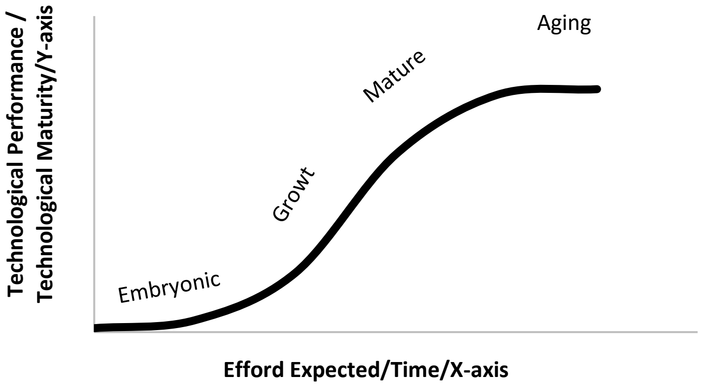


Figure 4.7. Technology growth S curve. Adapted from (Adamuthe & Thampi, 2019).

The growth curve of technology is based on a hypothesis that describes how technology advances and spreads. It represents the status of improvements in evolving technology standards as cumulative types over time. Simply stat, the principle uses time-series data to predict the rate of transition, assuming that the increase or spread in a particular technology fits a statistical formula (Ryu & Byeon, 2011). The technology growth curve shows the trend in the technological transition and can forecast changes in technology efficiency (Porter et al., 2011). Several models, such as the Bass diffusion model (BASS), Pearl, Gompertz, and Fisher–Pray models, can be used to produce a growth curve. The appearance or lack of symmetry is a noticeable contrast between the exceptional Pearl model and the Gompertz model. The difference originates in the pace of development and the inflection point (Ryu & Byeon, 2011). In the literature, the most commonly used growth curves for TF are logistic (Pearl) and Gompertz functions (Adamuthe & Thampi, 2019). Therefore, the Gompertz growth curve and logistic (pearl) curve were applied here to perform TF. The Gompertz growth equation and logistic growth curve are given in **Equations (4)** and **(5)**, respectively (Adamuthe & Thampi, 2019; Ryu & Byeon, 2011; Winsor, 1932), where *a* is the asymptote or carrying capacity, *b* is the displacement on the X-axis, and *c* is the growth rate.

Gompertz Growth Model: $$Y(t)=a.e^{(-b.e^{-k.t})} \tag{4}$$

Logistic Growth Curve: $$Y(t)=\frac{a}{1+b.e^{(-ct)}} \tag{5}$$

Multigenerational technology innovation happens as many emerging inventions begin to evolve in a single technology field and eventually expand around the globe. The technology integration growth is expected to increase dramatically at a specific point, then settle. After reaching a specific point, the technology requires longer to be adopted after reaching a specific maturity level (Oh, 1988). Relatively, the Gompertz growth model is asymmetrical to the inflection point ($Y = a/e$). The point of inflection occurs at $t = \frac{ln(b)}{e}$. The curve grows steadily until it reaches the inflection point, then the rate of growth decreases (Ryu & Byeon, 2011). Therefore, the Gompertz growth model was applied to predict the time required for the adoption of I4.0 and its technologies. As some researchers found a connection between the trend in biological development and the growth in a technology's performance capability, the logistic growth model was also used in this research to provide comprehensive consequences (Adamuthe & Thampi, 2019; Kucharavy & De Guio, 2015). The logistic growth model (Pearl) is symmetrical to the inflation point $Y = (a/2)$; the inflection point occurs at $t = \frac{lnb}{c}$ (Oh, 1988).

4.4 Chapter Results

A survey was designed to validate the proposed MM and F/W integrated with TF in a real-time scenario. Therefore, a case study was conducted based on a large automobile part manufacturing enterprise that employs more than 1500 people in Turkey. The objective of the survey was to evaluate I4.0 adoption and the maturity of the enterprise based on the proposed MM integrated with readiness F/W. Respondents from different departments were required to evaluate the I4.0 maturity of the enterprise in four different dimensions: (1) Factory 4.0, (2) Management 4.0, (3) Logistics 4.0, and, (4) Operator 4.0. A total of 30 people working at the enterprise took part in the online survey to assess the I4.0 technology adoption of the enterprise. The survey results were obtained from SurveyMonkey and data calculations and analyzes were performed in Microsoft Excel. The I4.0 technology integration of the company was evaluated, and the findings from the survey were reported to the company. The report included the current I4.0 maturity level of the company based on the proposed MM F/W and the growth curve of the company toward complete I4.0 technology integration.

The work experience and expertise of the participants are presented in Figure 4.8 and Figure 4.9. The respondents mainly had 11–20 years of experience. The study mostly considered the expertise of process development engineers in the company.

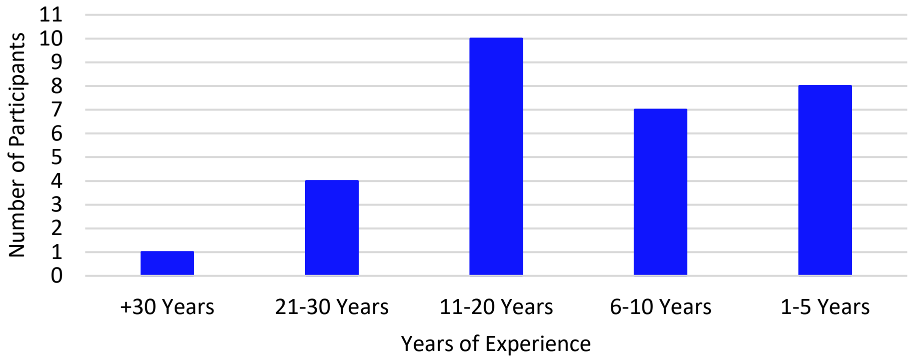


Figure 4.8: Work experience of participants.

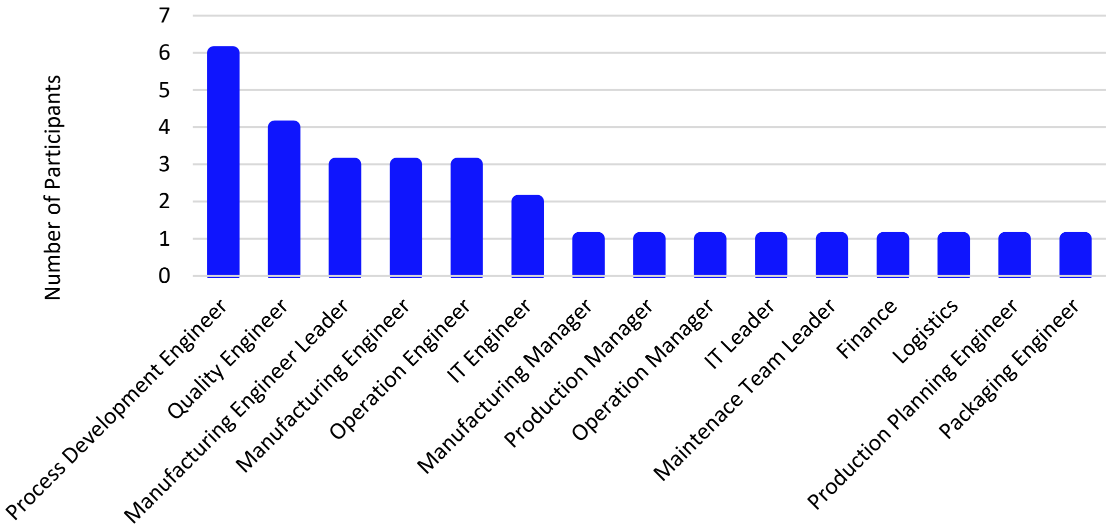


Figure 4.9: The expertise of the participants.

Based on the survey results, the enterprise's maturity level was obtained, as shown in Figure 4.10 and Figure 4.11. The company's overall maturity level was scored 2.73 out of 5.00. In other words, the company has 54.52% completed its I4.0 technology revolution. Each dimension was also evaluated: Factory 4.0 maturity level = 2.75/5.00, Logistics 4.0 maturity level = 2.74/5.00, Management 4.0 maturity level = 2.69/5.00, and Operator 4.0 maturity level = 2.73/5.00.

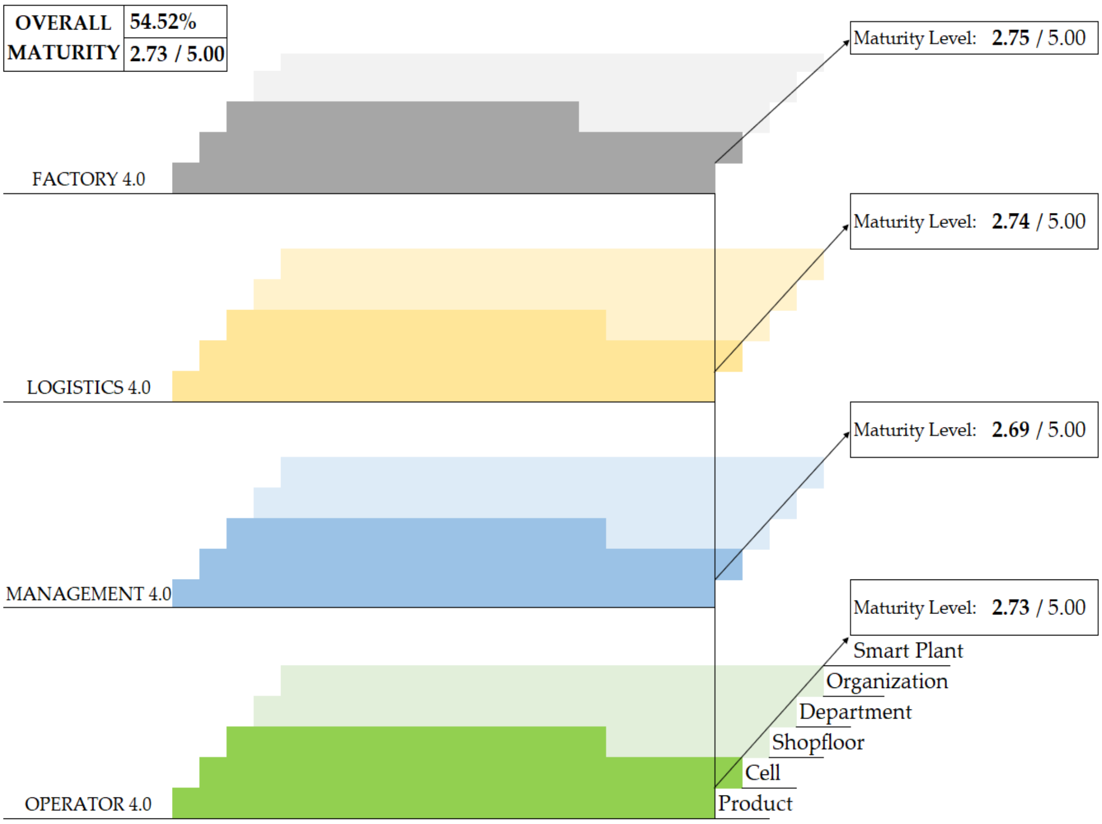


Figure 4.10: Enterprise's maturity level evaluation.

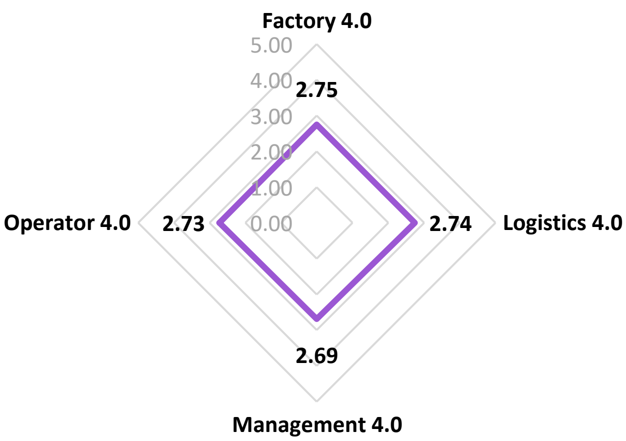


Figure 4.11: The overall enterprise maturity level of dimensions.

Each dimension has numerous sub-dimensions used to help identify the required technologies that were not considered by the enterprise in its I4.0 revolution. Factory 4.0 has 25 different sub-dimensions, as presented in Figure 4.12; Logistics 4.0 has 11 different sub-dimensions, as shown in Figure 4.13; Management 4.0 has 13 different sub-dimensions, as illustrated in Figure 4.14; and Operator 4.0 has 11 different sub-dimensions (Figure 4.15).

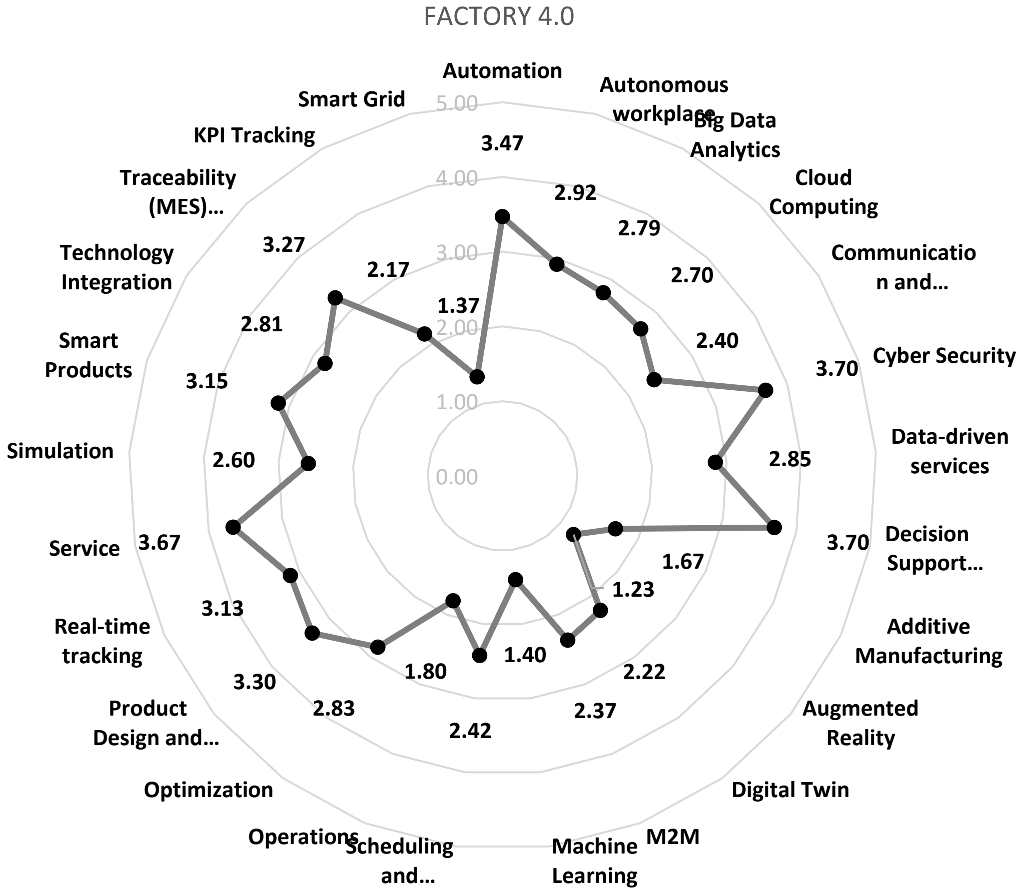


Figure 4.12: The maturity level of Factory 4.0 subdimensions.

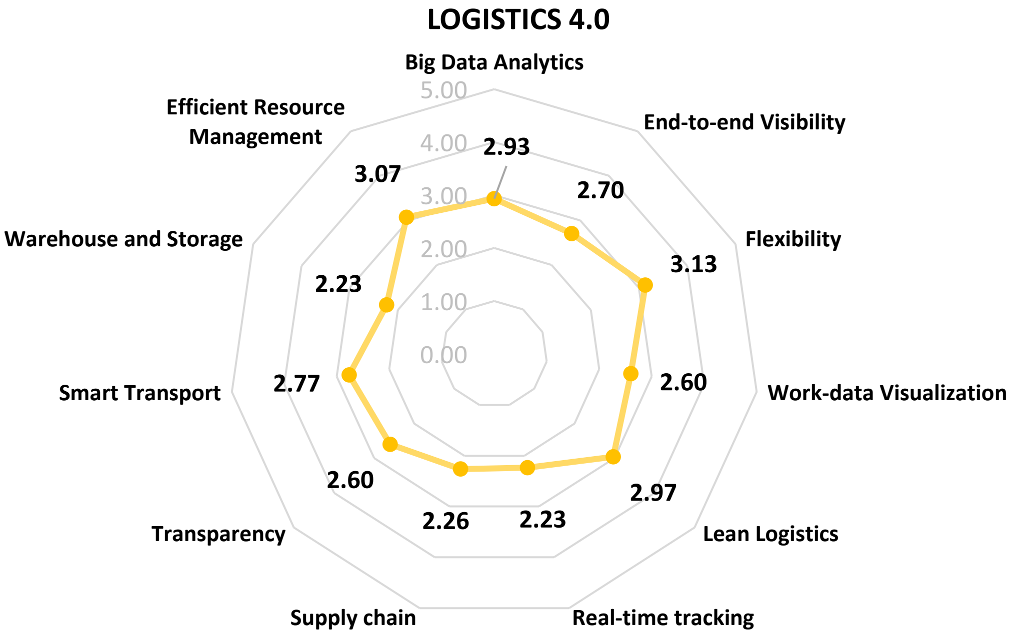


Figure 4.13: The maturity level of Logistics 4.0 subdimensions.

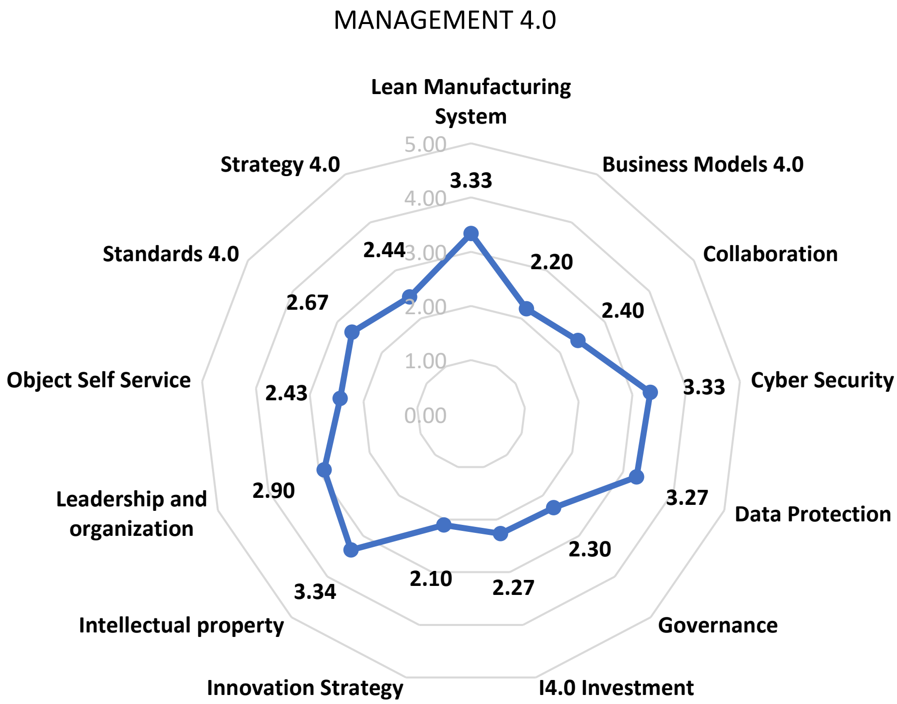


Figure 4.14: The maturity level of Management 4.0 subdimensions.

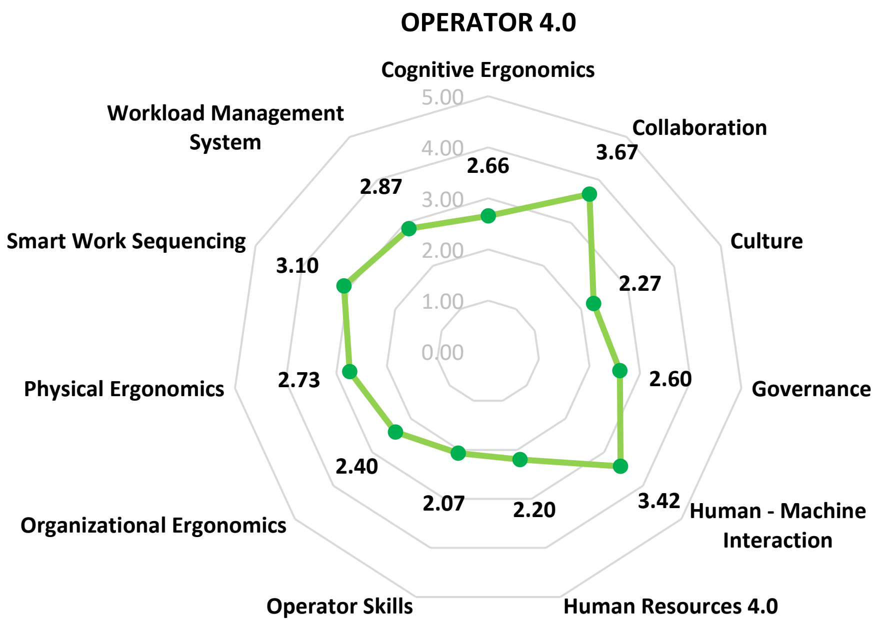


Figure 4.15: The maturity level of Operator 4.0 subdimensions.

The MM evaluation showed that the enterprise needs to pay more attention to the use of renewable energy sources, predictive/preventative maintenance, application of machine learning, application of augmented reality, and additive manufacturing technologies, which scored lower in the Factory 4.0 dimension. In the Logistics 4.0-dimension, warehouse and storage, real-time tracking, supply chain, and smart transport scored lower. In the Management 4.0-dimension, innovation strategy, business 4.0, strategy 4.0, and I4.0 investment scored lower. In the Operator 4.0-dimension, operator skills, human resources 4.0, governance, and culture scored lower. Overall, the company's maturity score was higher in the Factory 4.0 dimension and lower in the Management 4.0 dimension.

The maturity level of the company was evaluated, and we applied TF, which is presented as an S curve in Figure 4.16. Each dimension's maturity level is presented in Figure 4.17 and Figure 4.18. Based on the Gompertz model, the technologies required for Factory 4.0 are expected to be completely adopted by 2030; by 2031 for Logistics 4.0; for Management 4.0, by 2031; and 2031 for Operator 4.0. Overall, technology adoption was forecasted to be completed in 2031. Based on the logistic model, the technologies required for Factory 4.0 are expected to be completely adopted in 2030; for Logistics 4.0, by 2034; by 2034 for Management 4.0; and 2034 for Operator 4.0. Overall, technology adoption is forecasted to be completed in 2034.

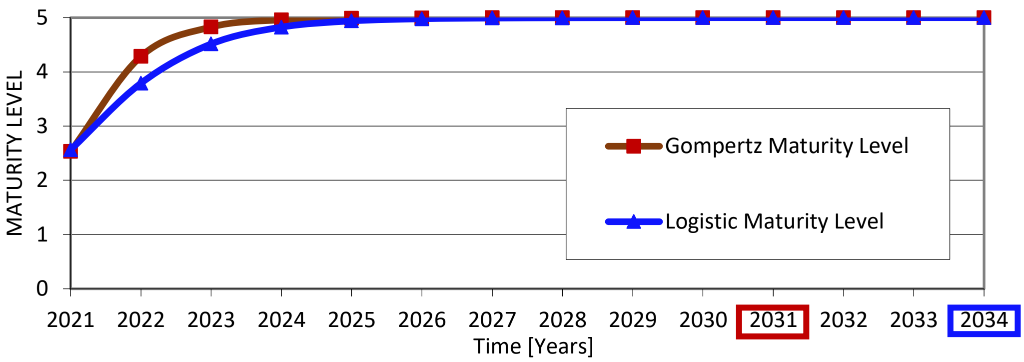


Figure 4.16: TF for the enterprise.

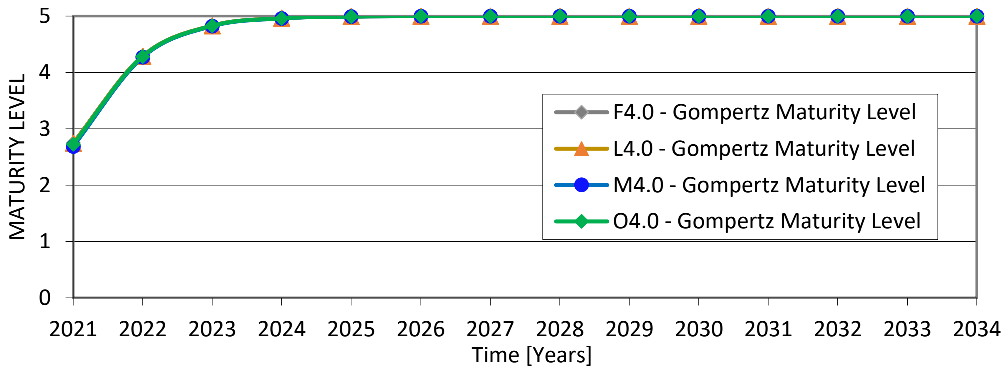


Figure 4.17: S curve of the Gompertz model for the I4.0 dimensions of the enterprise.

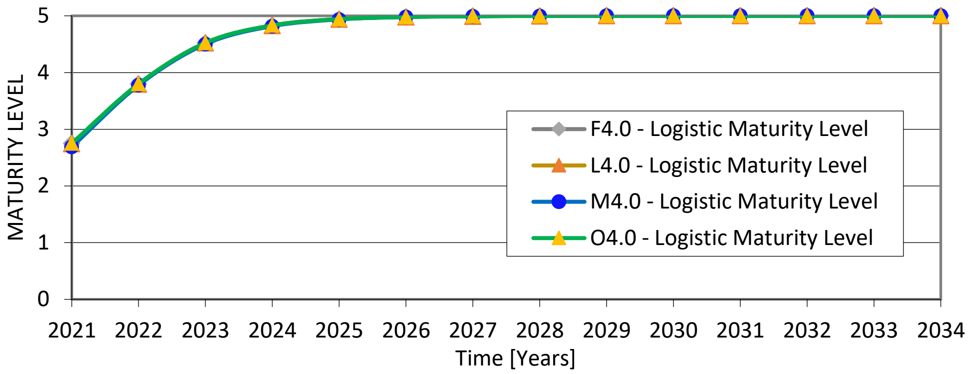


Figure 4.18: S curve of the logistic model for the I4.0 dimensions of the enterprise.

The methodologies of TF provide procedures for evaluating, displaying, and, in some cases, collecting data. There are four different types of forecasting methods (Council, 2010): (1) judgmental or intuitive methods, (2) extrapolation and trend analysis, (3) models, and (4) scenarios and simulations.

In this study, extrapolation and trend analysis methods were used for technological forecasting. The TF model must be tested to understand the model's efficiency. Therefore, the below terms were calculated and are provided in Table 4.6. The calculations proved that the model was sufficient to use. The forecasting performance, measured by root-mean-square error (RMSE), can roughly divide the models into three groups (N. Meade & Islam, 1995):

- RMSE < ~0.1
- < RMSE < ~0.2
- < RMSE

Table 4.6: Major performance assessment methods and metrics.

Technique and indicator	Concept	Operational Definition	Gompertz Model	Logistic Model
Mean Squared Error (MSE)	Average of the squares of the prediction errors	$\mathrm{MSE} = \frac{1}{\mathrm{n}}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2$	0.0372	0.0262
Root Mean Squared Error RMSE	Standard deviation of the prediction errors	$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{n}}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}$	0.1929	0.1619
Mean Absolute Error (MAE)	Average of the absolute difference between the prediction errors	$\mathrm{MAE}=\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}\lvert\mathrm{Y_i}-\hat{\mathrm{Y}}_{\mathrm{i}}\rvert$	0.1929	0.1619
Root Mean Squared Logarithmic Error (RMSLE)	Root mean squared log error	$\mathrm{RMSLE}=\sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}\left(\log(\mathrm{Y_i}+1)-(\hat{\mathrm{Y}}+1)\right)^2}$	0.0319	0.0266
Mean Absolute Percentage Error (MAPE)	Mean Absolute Percentage Error	$\mathrm{MAPE}=\sum_{\mathrm{i}=1}^{\mathrm{n}}\frac{\lvert\mathrm{Y_i}-\hat{\mathrm{Y}}_{\mathrm{i}}\rvert}{\mathrm{Y_i}}\mathrm{x}100$	7.08%	5.94%
Mean Absolute Deviation (MAD)	Mean Absolute Deviation	$\mathrm{MAD}=\frac{\sum_{\mathrm{i}=1}^{\mathrm{n}}\lvert\mathrm{Y_i}-\hat{\mathrm{Y}}_{\mathrm{i}}\rvert}{\mathrm{n}}$	0.0708	0.0594

Results show that the T/F model has a qualified efficiency to be carried out in this thesis.

Chapter 5

INDUSTRY 4.0 READINESS, ADVANTAGES AND CHALLENGES OF SMART MANUFACTURING ENTERPRISES IN TURKEY

Manufacturing industries significantly influence the financial and societal development of the countries. As being a commonly acknowledged term for universities and research & development centers, the I4.0 concept has gotten an impressive consideration in the research literature as well as manufacturing companies. Researchers give attention to understanding the concept, defining the key technologies, and developing methodologies to perform digital transformation while manufacturing companies focus on the integration of I4.0 technologies to companies. Although to the extensive research literature on I4.0, research studies are not well enough influencing the industry and researchers should collaborate with Turkish manufacturers to understand the readiness of I4.0. Also, the scope of the existing researches is limited to a few industrial sectors. Therefore, Understanding the I4.0 concept and its technologies is essential for manufacturing companies toward the I4.0 transition. It is also critical to consider advantages, challenges, and awareness of I4.0 technologies before creating a roadmap for the I4.0 transition. In this context, the objectives of this chapter are to (1) perform a SWOT analysis to understand the weaknesses, strengths, opportunities, and threats for Turkey toward the I4.0 transition, (2) identify the I4.0 readiness/awareness, I4.0 advantages, challenges and willingness to invest by surveying Turkish manufacturers, and also (3) have a detailed discussion on advantages and challenges foreseen in the transition to in the context of Turkey. Based on the findings, a foundation for further research is provided in this chapter.

5.1 Turkey Toward 4th Industrial Revolution

I4.0 is imminent for the manufacturing systems of the future. In Turkey, there are almost 200 automotive companies, and some of the import, the rest provide engineering services (Kılıç & Alkan, 2018). Therefore, Turkey can turn the fourth industrial revolution into an advantage if those companies produce their products rather than importing. Also, worth mentioning that creating new policies/activities is especially important to develop high-value-added studies such as a robot, software, and hardware projects with the association of companies and universities.

Turkey is advantageously located at the junction of Europe, Asia, and the Middle East, surrounded by the sea on three sides and eight neighboring countries and recognized as a regional hub for global business, both in terms of production and distribution (Switzerland Global Enterprise, 2017). According to (TUSISAD & BCG, 2017) and (BCG & TUSISAD, 2016) reports, Turkey has a competitive advantage in the global value chain owing to its geographical location providing logistic advantage, and relatively lower labor costs. This advantage provides new investments and new businesses to Turkey. Tecim and Tarhan (2020) observed that most of the industrial companies in Turkey, based on automation and use resource planning software and production management systems so that 4^{rt} industrial technologies such as cloud computing, big data, and horizontal and vertical system integration should be implemented to automation systems to get the maximum benefit from I4.0 in terms of productivity, flexibility, and efficiency (Tecim & Tarhan, 2020). Aylak, Kayikci, and

Taş (2020) stated that standardization of logistic prices can be transparent to everyone through the application of cloud technology. Also, real-time logistic tracking is another advantage for the logistic sector in Turkey.

Another significant advantage of Turkey can be the average population age of 29 (Yaşar & Ulusoy, 2019). The young population is expected to adopt new technologies faster and technological device usage statistics presented by (Tecim & Tarhan, 2020) show that the Turkish population spends a serious amount of time with technological devices. Therefore, the adoption of I4.0 technologies such as big data, cloud, IIoT can be easier than expected for Turkey.

There are certain challenges associated with the adoption of I4.0, as studied by the researchers, (BCG, 2017; EU, BCG, & TUSISAD, 2016; Gökalp, Gökalp, Çoban, & Eren, 2019; PricewaterhouseCoopers (PWC), 2014a, 2015; Roland Berger, 2017; Schröder, 2016; Stark et al., 2017; Weyer et al., 2015) and (Zhou et al., 2015). I4.0 revolution brings several challenges such as slowing down of investments in capital-intensive systems, delaying of the widespread use of new manufacturing technologies due to limited qualified workforce and ecosystems, accelerating employee turnover with the shift of workforce from industry to service sector, and delaying the formation of an experienced workforce. Placing special emphasis on training strategies for the formation of a qualified workforce that will be active in manufacturing can be considered a feasible strategy to overcome these obstacles (Öztürk, 2017). SWOT Analysis

SWOT provides a theoretical base-case analysis of Turkey for industrial sectors, as presented in Table 5.1. SWOT analysis is carried out to highlight the strengths, weaknesses, opportunities, and threats of Turkey while transforming to the fourth industrial revolution. The weaknesses of Turkey seem higher than strengths. However, opportunities are higher than threats. Therefore, the fourth industrial revolution in Turkey can be risky due to economic fluctuations and production quality. Nevertheless, opportunities can be turned into an advantage with the transformation.

Table 5.1: SWOT analysis for Turkish enterprises.

STRENGTHS	**WEAKNESSES**
1) Rapid export growth in the last decade. 2) Strong banking sector. 3) Developed and large domestic market. 4) Generous public incentives, aimed to increase private RDI, export share of high-tech industries, as well as to improve research Commercialization and entrepreneurship.	1) I4.0 and its technologies require a highly skilled workforce, but vocational education levels are low. 2) Need for a higher-skilled labor force. 3) Premature de-industrialization risk. 4) Low export share of high-tech products. 5) Unstable economy, geostrategic risks, and tension of Turkey's relationship with other countries can affect trades. 6) Unstable production percentage (average 30% defected product) and insufficient inspections limit developments. 7) Less contribution to innovation projects. 8) High operating costs.
OPPORTUNITIES	**THREATS**
1) Turkish manufacturers are expected to increase their productivity. 2) Turkey will gain a competitive advantage that can lead up to 3% of yearly additional growth of industrial production. 3) Provided Turkey roadmap for the fourth industrial revolution and planned industrial plant constructions in Turkey can create new opportunities. 4) Ministry of Science, Industry and Technology incentives for innovation encourages the population to be part of projects. 5) Energy change from gasoline to electricity creates new opportunities. 6) The Union of Chambers and Commodity Exchanges of Turkey (TOBB) and the Ministry of Science and Technology communities proposed a project for the production of the first domestic car in Turkey. This can encourage the population to create innovative solutions.	1) I4.0 requires high investment cost that will turnover in the following 5-10 years and Turkey's economy is not as good as to predict following 5-10 years. 2) Geopolitical risks in Turkey and World affecting economic growth. 3) Unstable economy prevents people to invest in technology. 4) Fluctuation in foreign currency affects capital stock and profit margin. 5) Borrowing-based investments, high industrial financing expanses destroy financing policies. 6) Asian producers get increasing global market share.

5.2 Survey-based Evaluation of Companies in Turkey

A survey-based questionnaire is specifically prepared for practical analysis of Turkish enterprises for understanding the readiness of I4.0, willingness to invest in I4.0, benefits, and challenges toward the industrial revolution. In total, the number of 100 people from various industrial sectors participated in the survey. The survey structure is provided in Figure 5.1.

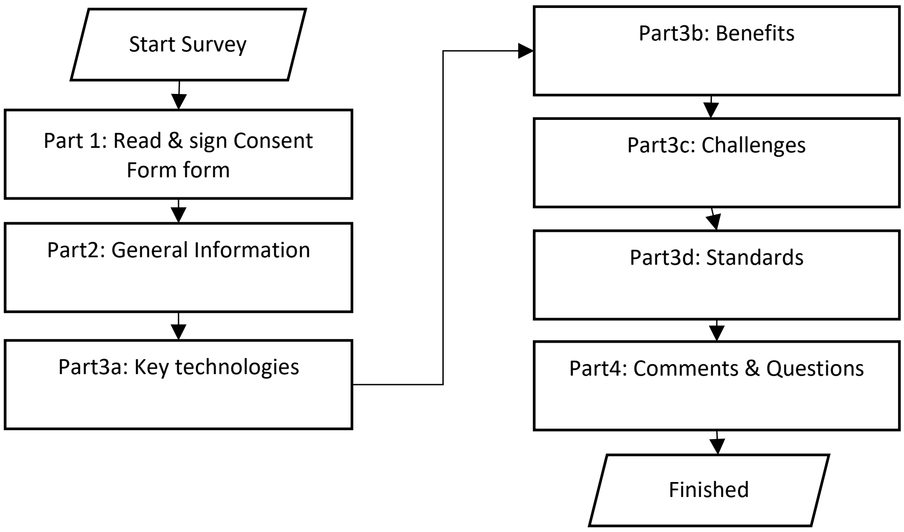


Figure 5.1: Survey flowchart.

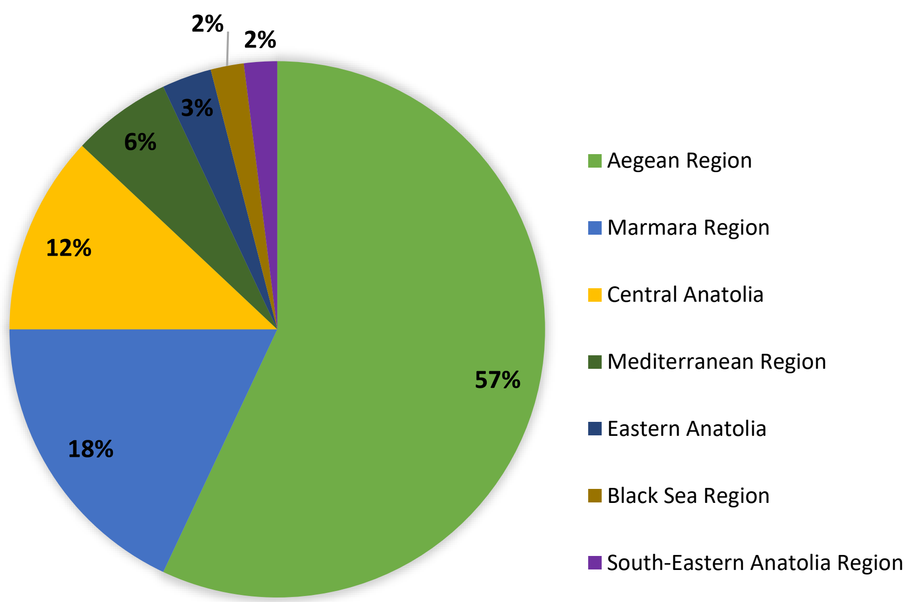
In business, people work on several projects at the same time, while in academia, most of them stick to a few projects at most. In addition to the scientific duties of planning and conducting theoretical experiments, the research scientist should also be responsible to turn experimental studies into real-world actions. Therefore, SWOT analysis and survey methods are applied in this paper to understand the level of readiness, awareness, actual challenges, and predicted benefits from the industrial companies in Turkey. Moreover, this study indirectly affects participants by raising awareness of the I4.0 key technologies.

5.3 Survey Findings

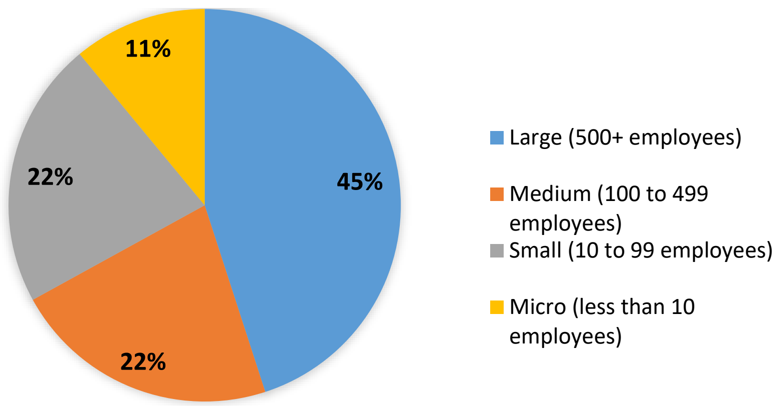
This research provides an insight into the potential of Turkey and the current situation of I4.0 in Turkey. Also, this study evaluates the level of I4.0 readiness, awareness, and willingness to invest in I4.0. This study is equally relevant for academicians as well as practitioners, as it delivers a critical analysis based on the status of companies in Turkey.

5.3.1 Industry 4.0 Readiness and Awareness

Participants from different companies and different industrial sectors contributed to this research toward the discovery of the I4.0 status of the companies in Turkey. The region, size, industrial sectors of the companies, respondents' level of management, respondents' work experiences are resented in Figure 5.2. Additionally, Figure 5.3 illustrated the industrial sector distribution of the companies that are participated in the survey.



A)



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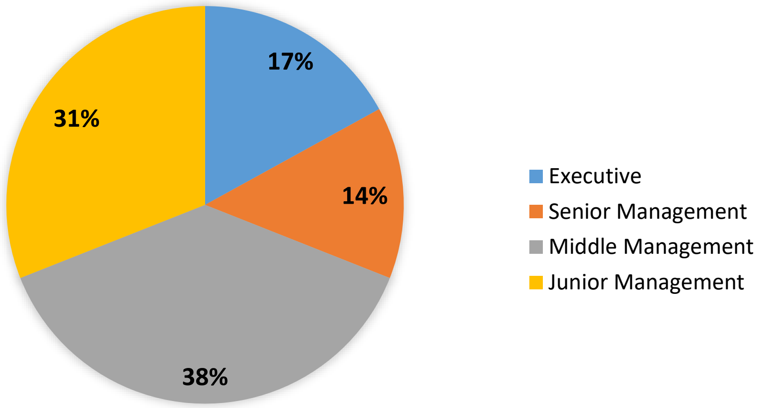
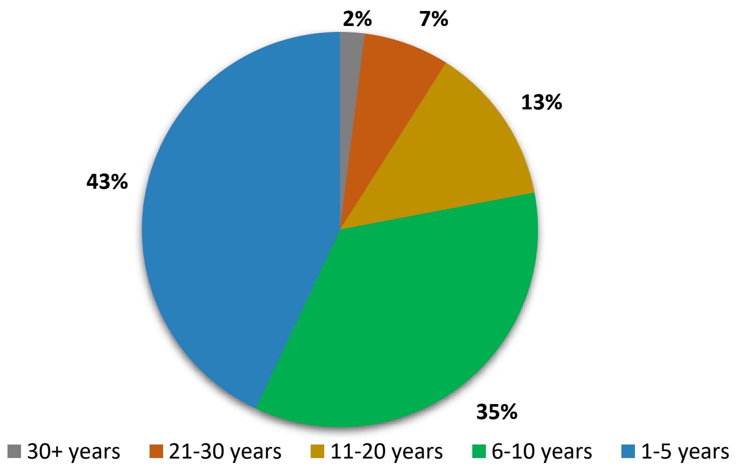


C)



D)

Figure 5.2: A) Region of the companies that are participated in the survey, B) Size of the Turkish manufacturers that are participated in the survey, C) Management level of the respondents, D) Experience of the respondents.

Turkey has 7 regions and each region has a different population size. According to the Turkish Republic of Interior Ministry (2021), seven regions are Marmara Region, Central Anatolia Region, Mediterranean Region, Aegean Region, South-Eastern

Anatolia Region, Black Sea Region, Eastern Anatolia region with a population size of 24.465.689, 12.705.812, 10.552.942, 10.318.157, 8.876.531, 7.674.496 and 5.966.101 respectively. The survey includes respondents from all regions of Turkey to provide a better estimation about I4.0 awareness. Survey results show that a high number of responses received from the Aegean Region and Marmara Region, as these regions include high population size and a high number of manufacturing companies.

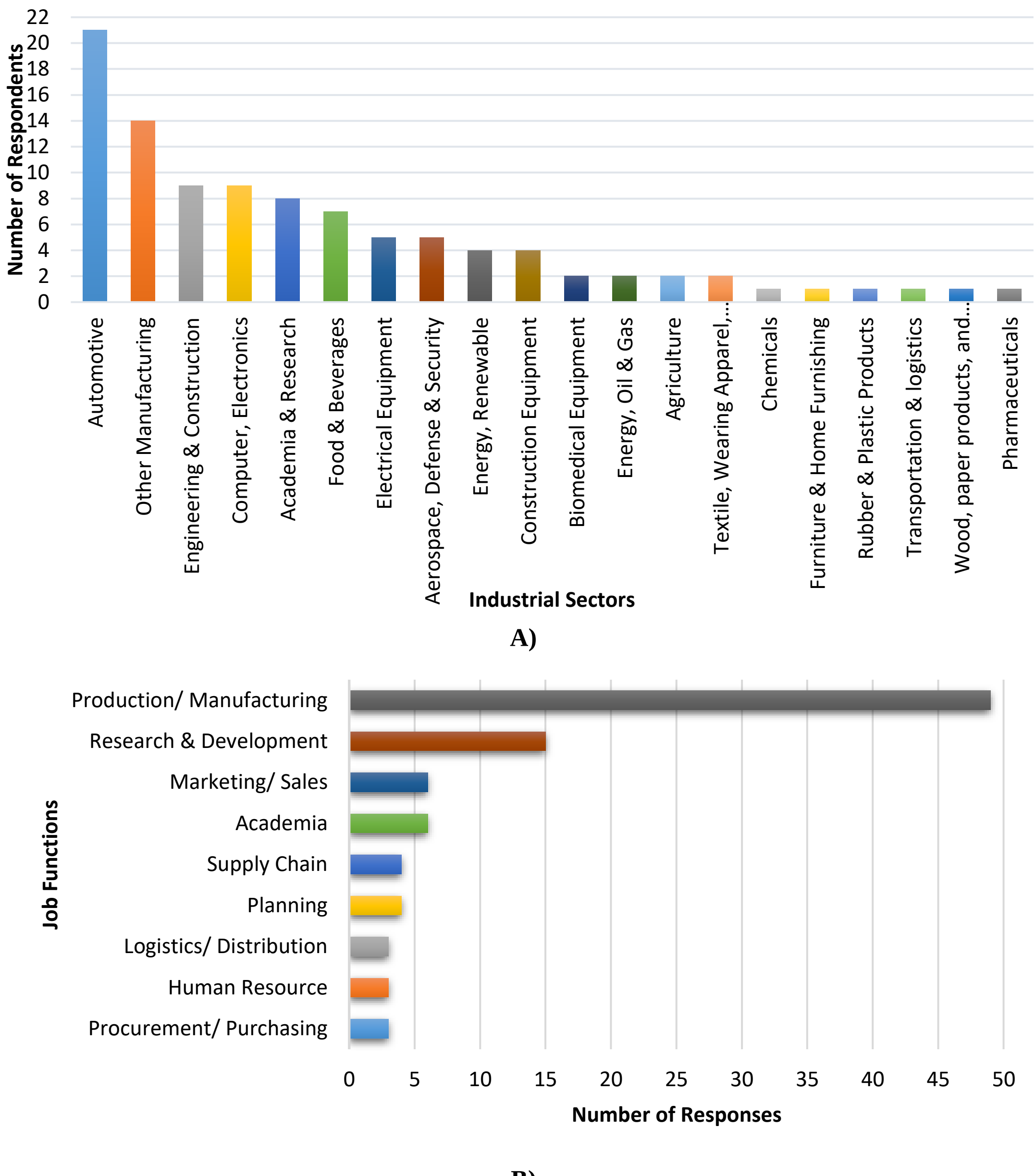


Figure 5.3: A) Industrial sector distribution of the respondents, B) Job function of the respondents.

More than 20 different industrials have been involved in this study, and the highest number of responses were received from the automotive sector and followed by Other manufacturing, engineering & construction, computer & electronics, academia & research, and food & beverages. Other manufacturing includes the tobacco sector, custom product/machine manufacturing, steel-iron manufacturing, finance, communications, and transport. The highest responses were received from the automotive sector as it is one of the leading industrial sectors in Turkey.

Job functions of the respondents are divided into nine categories and the majority of the respondents' job functions were observed as production & manufacturing. I4.0 key technologies are generally used on the shop floor. Therefore, the production/manufacturing job function can provide a better understanding of the awareness of I4.0 technologies. Nevertheless, for the overall estimation of I4.0 awareness and knowledge, results from other job functions are also required.

Awareness of I4.0 technologies are evaluated into 2 categories, 1) use of technology as of today, 2) expectation of technology usage within 2 years. Participant responses are illustrated in Figure 5.4. Results show that computer networks, databases, and computer-aided design are the most commonly used I4.0 technologies as of today. However, only a few companies use the following technologies; freemium, object self-service, e-kanban, artificial intelligence, and augmented reality. Moreover, most of the companies expect to use MES integration, object self-service, sustainable supply chain design, predictive maintenance, and IIoT technologies within 2 years. Tele-maintenance, machine learning, intellectual property protection, and cybersecurity technologies are focused on by companies to put in use in the long term.

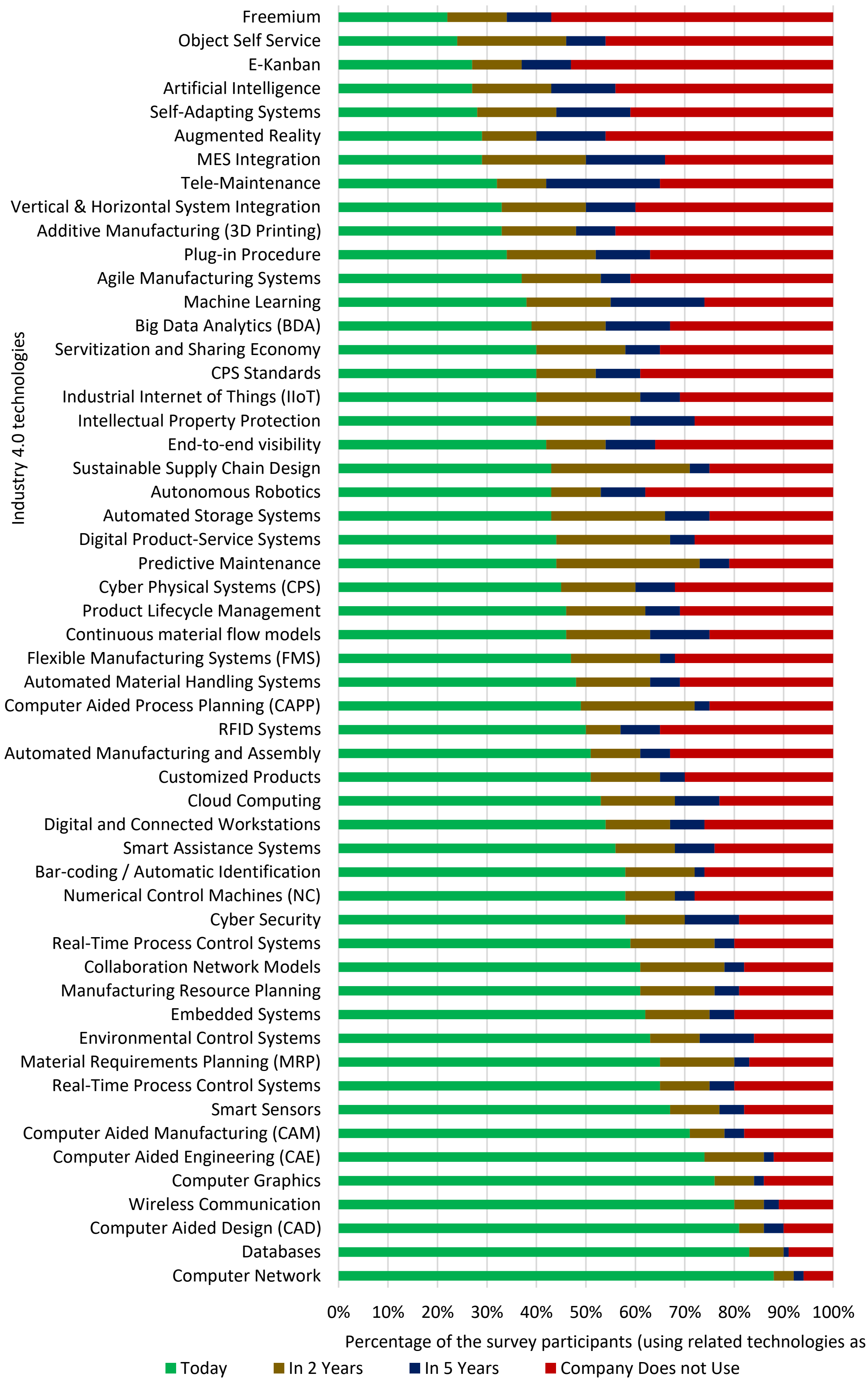


Figure 5.4: Use of the I4.0 technologies.

5.3.2 Advantages of Industry 4.0 for Turkey

Significant advantages of I4.0 are highlighted in the introduction as a theoretical study. Based on the theoretical study, practical evaluation is performed on participants who work at real-world companies in Turkey. Participant responses presented in Figure 5.5 and responses highlighted the significance of the I4.0 advantages that are obtained from the literature.

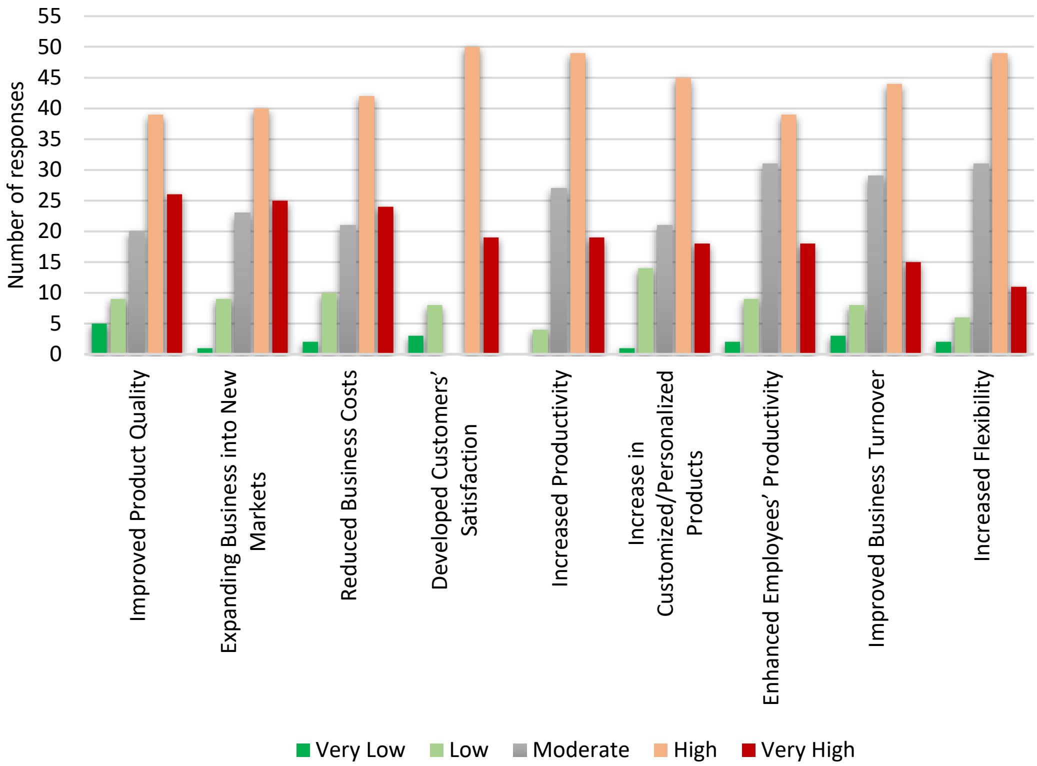


Figure 5.5: Advantages of Turkey toward I4.0 transition.

5.3.3 Challenges and Risks Toward Industry 4.0 adoption for Turkey

Although there are several benefits of I4.0, there are also certain challenges associated with the adoption of I4.0. To understand the significance of the challenges toward the industrial revolution for Turkey, participant responses are analyzed and analyzes are presented in Figure 5.6.

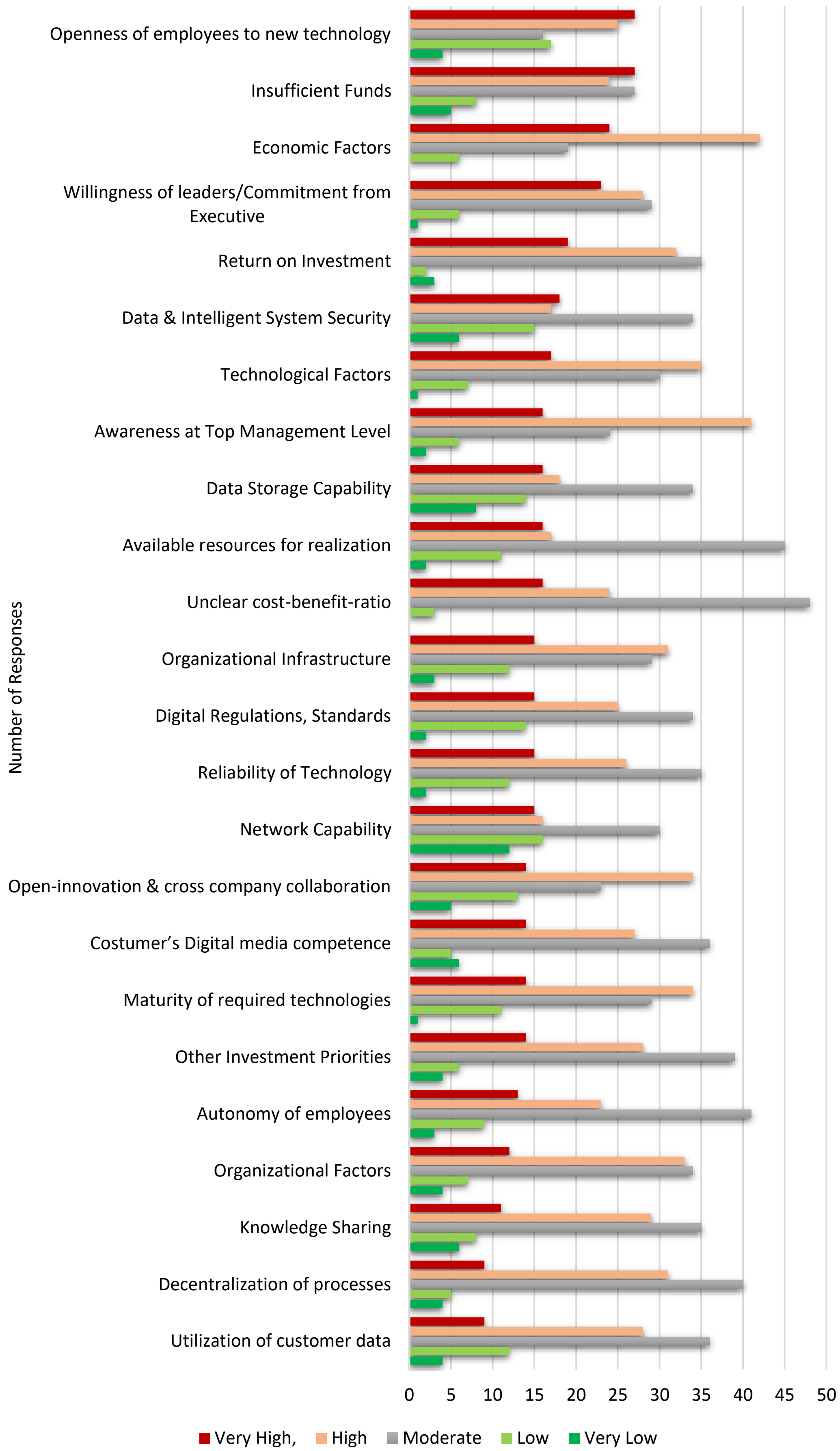


Figure 5.6: Challenges of Turkey toward I4.0 transition.

To provide an efficient, effective, and rapid transformation and adaption towards I4.0, standardization is required for products and processes across the globe. Therefore, considering participants' awareness of I4.0 standards become important to evaluate I4.0 readiness and awareness for companies. Figure 5.7 provides the awareness of standards and the use of standards in the company. 20 respondents are evaluated as none of the provided standards are used in their company.

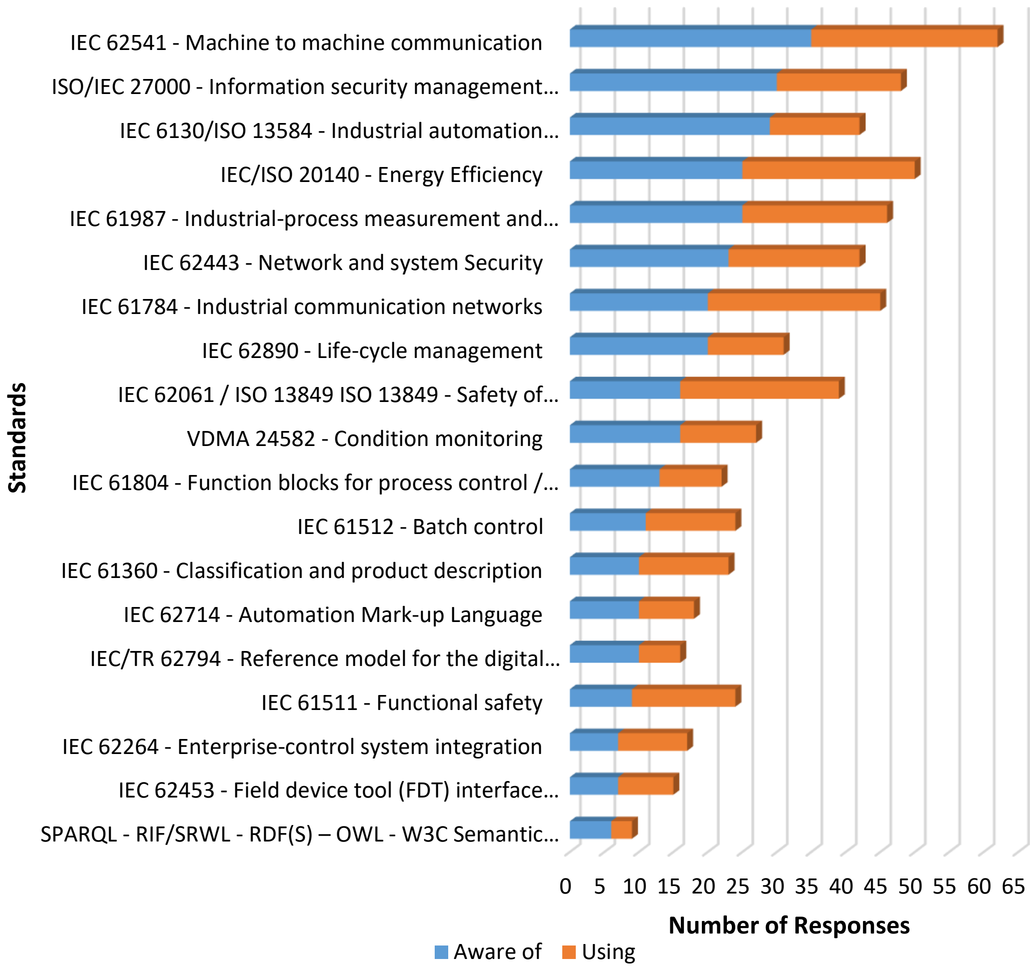


Figure 5.7: Awareness of the standards based on survey responses.

Besides, digitization enables businesses to increase the pace of creativity and transform speed and agility into a strategic advantage. This is the era where factories are smartly connected with high-tech tools to help prepare and handle personnel and processes.

Importance of the digitalization is more apparent during the economic crisis as well as pandemic outbreaks. To understand the effect of the COVID-19 pandemic outbreak in Turkey, a specific question is included in the survey questionnaire. Participant responses are shown in Figure 5.8.

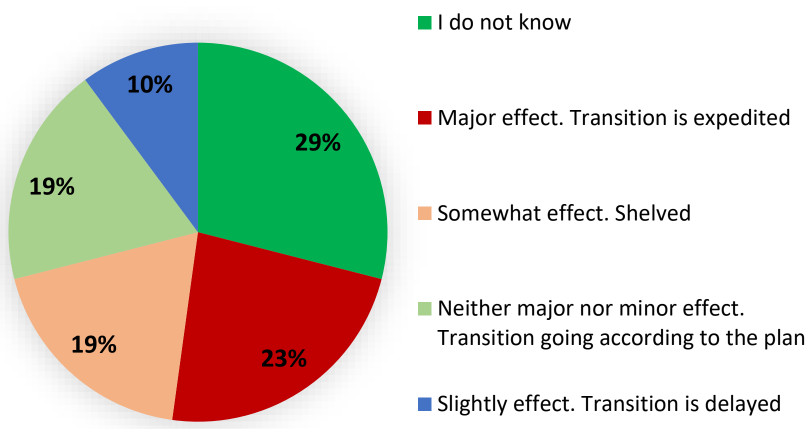


Figure 5.8: Effect of COVID-19 on Turkish manufacturers.

Survey results have proven that the COVID-19 pandemic outbreak is triggered the I4.0 transition to provide an agile manufacturing system that can be used to fight with a crisis such as COVID-19. 23% of the respondents think COVID-19 has a major effect on I4.0 transition is expedited. 19% of the respondents think COVID-19 has neither major nor minor effects and the transition is going as planned. 19% of the respondents think pandemic outbreak has a slight effect and I4.0 transition is shelved. 10% of the respondents think pandemic outbreak has a slight effect and I4.0 transition is delayed. The majority of the respondents have no clear knowledge about the effect of COVID-19 on the I4.0 transition.

Chapter 6

DISCUSSION

6.1 Proposed Maturity Model and Framework Model Integrated with Technology Forecasting

With an industrial background, we highlighted the theme of transitioning from a conventional manufacturing model to an agile, smart, and optimized manufacturing model. The literature review focused on MMs and F/W models, which resulted in the development of a viable MM based on a strong F/W. Several researchers have studied the incorporation of MMs into the determination of the I4.0 maturity level (Akdil et al., 2018; Back et al., 2015; De Carolis et al., 2017; Gökalp et al., 2017; Hankel & Rexroth, 2015; IMPULS, 2015; Jodlbauer & Schagerl, 2016; Lanza et al., 2016; Leyh et al., 2016; Menon et al., 2016; PricewaterhouseCoopers (PWC), 2016; Qin et al., 2016; Rockwell Automation, 2014; Günther Schuh et al., 2017; Schumacher et al., 2016; The University of Warwick (WMG), 2017). This subject has already been widely discussed in the literature, with a focus on the benefits of I4.0 and the potential challenges that enterprises will encounter when implementing these technologies (BCG, 2017; EU, BCG, et al., 2016; Mittal et al., 2018; Özlü, 2017; Park et al., 2018; PricewaterhouseCoopers (PWC), 2014a, 2015; Roland Berger, 2017; Schröder, 2016; Stark et al., 2017; Weyer et al., 2015; Zhou et al., 2015). Although the I4.0 vision is well-explained in the literature, less consideration has focused on the integration of I4.0 and proposing a F/W toward the I4.0 revolution for smart manufacturing enterprises. Therefore, research studies providing a bridge or link between academia and real-world businesses are lacking. None of the studied MMs from the literature fully cover all the criteria of scope, the fitness of purpose, completeness, clarify, and objectivity. We described the construction of a MM and F/W that cover all of the criteria to bridge the gap in the scientific literature. We provided TF to emphasize the technology growth for an enterprise. The proposed modular and generic MM has four dimensions, five levels, 60 second-level dimensions, and 246 sub-dimensions; the proposed MM F/W has four layers and seven hierarchy levels.

The research findings showed that the enterprise requires more attention regarding the use of renewable energy sources, predictive and preventative maintenance, the application of machine learning, the application of augmented reality, and additive manufacturing technologies in the Factory 4.0 dimension. In the Logistics 4.0 dimension, the enterprise should automatize the warehouse and storage systems, and real-time product tracking is recommended as a first step toward the I4.0 transition. In the Management 4.0 dimension, applications for awareness of I4.0 and cost-benefit strategy studies are suggested as the company has scored lower for these second-level dimensions. In the Operator 4.0 dimension, the definition of operator role in I4.0 relates to operator skills, and I4.0-based training to enable smooth technology integration.

Examining the findings, the maturity of the company was presented in a 3D F/W structure, providing readers a more detailed picture of the company. The findings showed that how the company individually engaged in a strategy of I4.0 adoption that other enterprises in the same sector may not have pursued. The company's overall maturity score was found to be 2.73 out of 5.00. The maturity of the company was considered with the proposed F/W and the company was evaluated to be at the Cell

Level of hierarchy in which the company is in the early stage of the I4.0 integration. Based on the TF findings, the forecasted year of full integration of I4.0 is between 2031 and 2034 if the enterprise takes actions to create a roadmap toward a smooth I4.0 transition.

The enterprise should follow these actions as a roadmap in the early stage of technology integration:

- Develop concepts for pilot projects and conduct a cost-benefit analysis based on existing use cases from research or industry associations;
- Develop pilot applications of artificial intelligence for processes and machines;
- Continually improve data collection and review the corresponding system of indicators and targets;
- Quantify the benefits of data collection;
- Examine what information can be obtained from the data already collected. Can patterns be identified? Do they provide the basis for simulations? Do they yield a consistent digital model of the value-added and which gaps need to be closed?
- Information sharing is still limited to only a few departments. An analysis should be run to determine where bottlenecks exist between systems and where potential can be leveraged by integrating information sharing into the system.
- Production should be analyzed to determine where it makes sense to introduce autonomous control into processes. Partnering with other companies or sharing knowledge with research institutions can help hasten progress.
- The areas in which IT security solutions are needed should be defined.
- A clear scheduling and maintenance strategy should be adopted.

- To achieve greater I4.0 readiness, it is important to gradually expand the add-on functionalities of products.
- Identify the areas in which potential could be leveraged by offering augmented reality.
- I4.0 is already being implemented in departmental pilot initiatives, but the strategic relevance is lacking. A viable I4.0 strategy must be developed.
- Cost-benefit analysis of I4.0 investment should be periodically included in top management meetings.
- Include operators in communication and socio-technology meetings that involve the policies of the organization, processes, and structures.

The maturity level of the enterprise was evaluated based on the proposed F/W structure. For Factory 4.0, Logistic 4.0, Management 4.0, and Operator 4.0, the company's maturity level was evaluated as 2.75/5.00, 22.74/5.00, 2.69/5.00, and 2.73/5.00 respectively. Then, the overall maturity level was calculated as 2.73/5.00, which means the company has reached 54.52% of I4.0 integration based on the proposed F/W. Therefore, the company requires significant effort to complete the I4.0 integration. Smart grid, simulation, smart operations, scheduling, and maintenance, augmented reality, and additive manufacturing was the second-level dimensions recognized as insufficient in the Factory 4.0 dimension. Smart warehouse and storage and real-time tracing were the second-level dimensions recognized as lacking in the Logistics 4.0 dimension. For Strategy 4.0, innovation strategy and governance were the second-level dimensions requiring more attention for the enterprise in the Management 4.0 dimension. The enterprise needs to make additional effort in the cognitive ergonomics and operator culture in second-level dimensions of the Operator

4.0 dimension. Comparing all dimensions, Factory 4.0 had the highest maturity level and Management 4.0 had the lowest. Based on our findings, creating a roadmap toward I4.0 integration is strongly suggested for the enterprise.

TF helped us to predict the year of completion of the I4.0 integration. Two different TF models were used to produce more accurate predictions. The Gompertz model predicted the completion of I4.0 integration as 2031, whereas the logistic model predicted the completion in 2034. Forecasting model performance was also considered by calculating the standard deviation of the prediction error (RMSE) and the mean absolute percentage error (MAPE), which were calculated as 0.1929 and 7.08% for the Gompertz model, and 0.1619 and 5.94% for the logistic model, respectively. When both models were compared, the expected year of full I4.0 integration is between 2031 and 2034.

6.2 Industry 4.0 Readiness, Advantages and Challenges of Smart Manufacturing Enterprises in Turkey

I4.0 is a vision that describes the industry of and for the future, moving towards higher productivity with flexibility, making it possible to manufacture highly individualized products under the economic conditions of mass production. Since its introduction in Germany, I4.0 is now a worldwide concept. The world is on the brink of I4.0, and there is an intent to implement I4.0, the global manufacturing industries are still in the progress of discovering the benefits and challenges of I4.0. The principle concept of I4.0 raised and implementation of 4^{rt} industrial revolution to middle and large enterprises has been started in the industry. In academic literature, applications, advantages, and challenges for Turkey are discussed. The research on I4.0 technologies has increased significantly over the last decade.

After deep literature scanning, it is understood that researchers, (Aegean Region Chamber of Industry, 2015; Audit Tax Consulting Corporate Finance, 2015; Aydemir, 2018; BCG, 2017; BCG & TUSISAD, 2016; Bulut & Akçacı, 2017; Bychkov et al., 2017; EU, BCG, et al., 2016; Gabaçlı, 2017; Genc, 2018; Koca, 2018; Küsters et al., 2017; Mittal et al., 2018; Özkurt, 2016; Öztürk, 2017; PricewaterhouseCoopers (PWC), 2014a, 2015; Roland Berger, 2017; Sak & Inan, 2015; Switzerland Global Enterprise, 2017; Tubitak, 2016; Tuncel & Polat, 2016; TUSISAD & BCG, 2017; Weyer et al., 2015; A. Yildiz, 2018; Zhou et al., 2015) have studied the adoption of I4.0 technologies in Turkey, and have highlighted the advantages and challenges associated with it, however, mostly their research is limited to a few industrial sectors. Identifying the I4.0 advantages, and challenges requires extensive practical studies in various industrial sectors that are critical for Turkey. In this paper, SWOT analysis was carried out to observe the current status of Turkey, and then, a survey-based questionnaire is developed to get responses from people who work in real-world companies from various industrial sectors in Turkey. In this way, it is aimed to understand awareness of I4.0, I4.0 advantages, challenges, and willingness to invest in I4.0 in Turkey.

The application of SWOT analysis demonstrated that Turkey has a wide domestic market in its strengths. Manufacturers and initiatives expect to increase the competitiveness and this can be listed in opportunities. Besides, Turkey's prominent weaknesses are observed as insufficient skilled labor force and unstable economy. Therefore, high investment costs can be evaluated as threats. As high investment cost leads to slow turnover, investing on I4.0 can be seen as risky for people who willing to invest.

This research was carried out based on a practical study including survey analysis in various industrial sectors to evaluate I4.0 awareness, knowledge and also identify actual and potential benefits of I4.0 for Turkey. More than 20 different industrials have been involved in this research, and the highest number of responses received from the automotive sector and followed by other manufacturing, engineering & construction, computer & electronics, academia & research, and food & beverages. Other manufacturing includes the tobacco sector, custom product/machine manufacturing, steel-iron manufacturing, finance, communications, and transport. The highest responses were received from the automotive sector as it is one of the leading industrial sectors in Turkey. Job functions of the respondents are divided into nine categories and the majority of the respondents' job functions were observed as production & manufacturing. I4.0 key technologies are generally used on the shop floor. Therefore, the production/manufacturing job function can provide a better understanding of the awareness of I4.0 technologies. Nevertheless, for the overall estimation of I4.0 awareness and knowledge, results from other job functions are also required.

Research findings show that computer networks, databases, and computer-aided design are the most commonly used I4.0 technologies as of today. However, only a few companies use the following technologies; freemium, object self-service, e-kanban, artificial intelligence, and augmented reality. Moreover, most of the companies expect to use MES integration, object self-service, sustainable supply chain design, predictive maintenance, and IIoT technologies within 2 years. Tele-maintenance, machine learning, intellectual property protection, and cybersecurity technologies are focused on by companies to put in use in the long term.

The main reason for the rapid increase in I4.0 technology usage can be economic disruptions due to the COVID-19 pandemic outbreak because survey results have proven that the COVID-19 pandemic outbreak is triggered the I4.0 transition to provide an agile manufacturing system that can be used to fight with a crisis such as COVID-19. 23% of the respondents think COVID-19 has a major effect on I4.0 transition and transition is expedited. 19% of the respondents think COVID-19 has neither major nor minor effects and the transition is going as planned. 19% of the respondents think pandemic outbreak has a slight effect and I4.0 transition is shelved. 10% of the respondents think pandemic outbreak has a slight effect and I4.0 transition is delayed. The majority of the respondents have no clear knowledge about the effect of COVID-19 on the I4.0 transition.

Benefits from adopting I4.0 are observed based on participant responses as increased productivity, real-time data collection, and faster decision making. Investing in I4.0 will cause a tectonic change in Turkey's economic productivity and a greater share of the global supply chain, resulting in more opportunities for a highly trained workforce. Challenges identified as openness of employees to new technologies, the autonomy of employees, awareness of top management, technological factors, and insufficient funds. Participants emphasized that the operator role is not well understood in I4.0.

Survey findings also present that some of the critical I4.0 standards are rarely in use such as IEC/TR 62794 and SPARQL protocol. Also, most of the participants are not even aware of some standards; IEC/TR 62794, IEC 61511, IEC62264, IEC62453, and SPARQL protocol. Nevertheless, IEC 62541, IEC 27000, IEC 6301, IEC 20140, and IEC 61987 are observed as the most commonly used and known standards.

People would like to invest in I4.0 technologies however, unclear cost benefits prevent people to take action toward the I4.0 transition. Participants are well aware of the significance of adopting I4.0. The adoption of I4.0 is being taken seriously in Turkey, as it presents an opportunity to advance Turkey's economy. Inability to adapt may lead the Turkish manufacturers to disruption. The transition can be smooth or disruptive depending upon the coherence between the key stakeholders. To ensure a speedy and smooth transition to I4.0, the Government, universities, and manufacturers, must take joint initiatives to develop a multi-pronged strategy to expedite the awareness and capacity building for the adoption of I4.0 technologies:

- Conduct special seminars and workshops, and training of I4.0 technologies to develop a workforce capable of meeting future challenges.
- Get everyone from different fields and organizations in the public and private sectors together to make shared decisions on standards and I4.0.
- Encourage SMEs to adopt I4.0 technologies by providing special tax exemptions on equipment for smart manufacturing and smart products.
- Increasing the availability of financing earmarked to I4.0
- Universities and vocational training colleges must revise their curriculum to incorporate courses relevant to I4.0 technologies so that the graduates are well equipped to meet the challenges in the industry. Alternative curriculum platforms must now be used by universities, like distant learning, online learning, open universities, and mobile apps for providing training on I4.0 technologies.
- The companies should also invest in training and skill enhancement of existing employees and workforce due to their knowledge and experience of the current manufacturing processes.

Nevertheless, any prospective increase in the number of occupations with routine tasks will be substituted by new technologies and eventually will result in mass unemployment. A number of jobs and occupations (technicians and associate professionals, clerks, service workers, and shop and market sales workers, plant and machine operators and assemblers) might be affected adversely and thus easily substitutable by new technologies because the tasks that they perform are routine. Technological changes have always acted as employment destroyers and employment generators. Some unique jobs which new technologies and transversal skills are extensively used can be promoted. Employees will face new challenges and will fill roles that are more demanding in the future. Thus, they should receive adequate preparation, and support in their personal development and training. Therefore, flowing with change by care, caution, and wisdom will bring more wealth and peace to Turkey.

This thesis explored that productivity gains of adopting I4.0 were not observed across all industries. When a small/medium firm adopts the I4.0, the human capital improvement and process redesign needed for a productivity increase are difficult to achieve in a short period, and the firm may have insufficient organizational capacity to utilize the IT application system. Each industrial sector has different core technologies. For instance, manufacturing sector requires automatized and intelligent production, Sales sector requires organized, smart storage systems and IT systems to provide customer demands on time. Therefore, it is critical to define the core technology of the company to start implementing I4.0. This variation makes the understanding of I4.0 complicated by the industrial sectors.

Although Germany is leading the I4.0 strategy, I4.0 holds huge potential for manufacturing industry in Turkey compared to other countries because Turkey's geostrategic location provides a global hub where trade is possible with all over the word. Therefore, Turkish enterprises should have benchmark with I4.0 leading companies during the I4.0 initiation. So, new suppliers might be generated in Turkey and they work with global companies that have already integrated I4.0. By this way, technology integration to Turkish enterprises can be smooth and easier.

This research provides an insight into the potential of Turkey and the current situation of I4.0 in Turkey. This study is equally relevant for academicians as well as practitioners, as it delivers a critical analysis of recent research and survey-based knowledge collection on Turkey's status in the context of I4.0.

6.3 Research Limitations

While conducting this study, we have used a large number of survey questions required to evaluate the company's maturity level. The limitation of the study was finding participants who were aware of I4.0 from the management level and were willing to answer the survey questions. Also, the respondents' understanding and experience played a vital role in the precise evaluation of maturity model. However, respondents may not feel encouraged to provide accurate, honest answers, also respondents may not feel comfortable providing answers that unfavorably present themselves. Here, our research is limited to the answers provided by the respondents. As a result, this research is limited to the responses provided by the participants, restricting the maturity assessment as a reference to the participants' expertise.

Another research limitation is the number of survey participants and our research is limited to the data collected from 27 participants for Maturity level evaluation of a manufacturing company and 100 participants for I4.0 readiness and awareness evaluation in Turkey. If the number of participants increases, the evaluation results can be changed accordingly.

6.4 Future Recommendation

This paper also provides a foundation and motivation for further research. Areas of recommended further research include:

- The application of the proposed MM and F/W to various companies in other industrial sectors.
- The application of the proposed MM and F/W to various companies in the same country or same region to assess the I4.0 maturity level of the country or region.
- A combination of more than one MM can provide better accuracy for I4.0 adoption compared with the use of an individual model.
- Other technology forecasting methods can be applied.
- Higher number of participants can be included in maturity level evaluation for the manufacturing companies to get better and precise results.

Chapter 7

CONCLUSION

I4.0 is a vision defining the future of the industry. The potential lies primarily in high-flexibility, resource-friendly, and high-productivity manufacturing. It enables highly customized products and goods to be mass-produced under the given economic conditions. Engineering, development, service, logistics, operation, and marketing are all interconnected in complex, real-time-optimized, value-added cross-enterprise networks. This thesis aimed to explore a large-scale automobile part manufacturing enterprise's adoption of I4.0 technologies by examining knowledge and implementation of I4.0 technology through engineering businesses, future gains from this development, and significant obstacles in transitioning to I4.0.

This thesis focused on the awareness, knowledge, readiness, adoption, willingness to invest, challenges, and benefits of I4.0. A questionnaire was designed for primary data acquisition from a large manufacturing enterprise. Finally, based on the availability of acquired data, a new MM and F/W model was developed and then applied to forecast the I4.0 technology adoption in the manufacturing enterprise. While conducting this study, we used a large number of survey questions required to evaluate the company's maturity level. The limitation of the study was finding participants who were aware of I4.0 from the management level and were willing to answer the survey questions. Therefore, the MM assessment is limited to the responses of participants obtained via the survey.

The aim was to investigate the adoption of I4.0 technologies in Turkey by exploring; the awareness and adoption of these technologies across engineering businesses; potential benefits from this development and major barriers and constraints faced while adopting I4.0. The research focused on the awareness, knowledge, readiness, willingness to invest, challenges, and benefits of I4.0 in Turkey. A questionnaire was designed for primary data acquisition. Finally, a new MM integrated with readiness F/W was developed and then applied to forecast the adoption of I4.0 technologies in Turkey.

This research will contribute to the following:

1) The proposed generic MM and modular F/W method integrated with TF provides insight into the current situation and growth of the smart manufacturing enterprise regarding I4.0 adoption, helps with the explicit identification of gap areas, and provides the foundation for policy decisions for I4.0 integration to maximize the potential of I4.0.
2) Explore the adoption, growth of I4.0 in Turkey.
3) Actual or potential business benefits from adopting I4.0 technologies in Turkey.
4) Understand the challenges, barriers, and factors of concern for adopting I4.0 technologies in Turkey.
5) Provide insight into the current situation and help explore solutions to problems and obtain the maximum potential of I4.0 in Turkey.

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APPENDICES

Appendix A: Proposed MM

No	1. Level Dimension	2. Level Dimension	I4.0 Concept	Maturity Level 1	Maturity Level 2	Maturity Level 3	Maturity Level 4	Maturity Level 5
1	Factory 4.0	Technology integration	Agile Manufacturing System	No flexibility of manufacturing system	Scalable manufacturing system	Modular and reconfigurable manufacturing system	Flexible manufacturing system	Agile/changeable manufacturing system
2	Factory 4.0	Technology integration	Automated Manufacturing & Assembly	Manual manufacturing or assembly	Mechanically assisted manufacturing or assembly	Semi-automated manufacturing or assembly	Fully automated manufacturing or assembly	Flexible automated manufacturing or assembly
3	Factory 4.0	Technology integration	Continuous and uninterrupted material flow models	Job Shop production	Cellular manufacturing	Production line	Continuous flow flexible production cell/line	Continuous flow flexible job shop
4	Factory 4.0	Technology integration	Plug-in Produce	No plug-and-produce	Use of internally made customized connectors	Use of existing standard connectors	Plug and produce of power supply and data communication with need of configuration	Plug and produce of power supply and data communication without any need of configuration
5	Factory 4.0	Autonomous workplace	Self-Adapting Manufacturing Systems	No adaptability of the manufacturing system	Manual reconfiguration of manufacturing system	Semi-automated reconfiguration of manufacturing system	Automated reconfiguration of manufacturing system	Self-adapting and intelligent manufacturing system
6	Factory 4.0	Autonomous workplace	Autonomous Robotics	No Robots used	Robots are used for repetitive duties	Autonomous robot applications are planned and pilot applications are available	Autonomous robots are integrated in specific areas	Automatic robots are widely used in production
7	Factory 4.0	Data-driven services	Integrated and Digital Real-Time Monitoring Systems	Only paper-based monitoring system	Partial Monitoring Systems	Partial Real-Time Monitoring Systems	Integrated Monitoring System	Integrated Real-Time Monitoring System

8	Factory 4.0	Data-driven services	Remote Monitoring of Products	Products are not monitored after delivery	Products are monitored spot wise by the customer or a sales agent or a technician	Products are monitored by the manufacturer through periodic condition checks	Products are digitally monitored by the manufacturer through remote access	Products are monitored and controlled through remote access
9	Factory 4.0	Robotics and Automation	Smart Assistance Systems	No decision-making support	System-based information about decision making	Data driven triggering of decision making	Data driven support for centralized decision making	Data driven support for decentralized decision making
10	Factory 4.0	Digital Modelling	Digital Twin	No digital twin available	Digital twin applications are taken under consideration and planning to implement pilot applications	Pilot digital twin applications are used in specific areas	Digital twin applications are widely used	Professional application of digital twin through skilled internal experts
11	Factory 4.0	Digital Modelling	Computer Aided Manufacturing (CAM)	No CAM available.	Traditional manufacturing systems are used but there are pilot applications of CAM	CAM helps operators to operate the machines	CAM is implemented to all machines and CAM based production available	CAM is implemented to all machines and CAM based production available. Also, internal skilled labor available and regularly trains.
12	Factory 4.0	Digital Modelling	Additive Manufacturing (3D Printing)	No use of Additive Manufacturing	Use of Rapid Prototyping provided by specialized firms	Acquisition of basic 3D printing or rapid prototyping technology	Acquisition of advanced 3D printing, 3D scanning or rapid prototyping technology	Additive Manufacturing integrated in the production system
13	Factory 4.0	Digital Modelling	Augmented Reality	No use of VR	360° Videos	Virtual Reality	Augmented Reality	Mixed Reality

14	Factory 4.0	Big Data	Big Data Analytics	no use of existing data	minimal use of existing data based on Excel or similar	collect data in a structured way and perform big data analytics projects through external experts	collect and analyze production and logistics data for process optimizati on with big data analytics tools	profession al application of big data analytics through skilled internal experts (productio n data analysts)
15	Factory 4.0	Big Data	Traceabilit y (MES) Integratio n	No MES system	MES system partially implement ed	Production Planning and Control system used for material requiremen t planning	Production Planning and Control system used for material requireme nt planning	MES system or similar implement ed but not integrated with ERP
16	Factory 4.0	Big Data	Cloud Computin g	Data is archived on single computer hard drives	Data is archived in a server structure	Data is accessible via VPN from outside the company	Software as a service models to avoid installatio n of applicatio ns on PC	Data is archived in a cloud system
17	Factory 4.0	Machine Learning	Artificial Intelligenc e	No applicatio n of AI	Reactive Machines	Limited Memory	Theory of Mind	Self-Awareness
18	Factory 4.0	IT supporte d business	Industrial Internet of Things (IIoT)	No IoT infrastruc ture	Sensors/ac tuators in production and Wi-Fi or wired LAN for data transfer	Data to informatio n - make data available for everyone	Cognitive analysis and custom apps to optimize processes	Self-configurati on, adjustment and optimizati on based on data
19	Factory 4.0	Smart Products	Identificat ion and Tracking Technolog y	No identifica tion technolog y	Barcode label	QR-Code or similar	Passive RFID tag	Active RFID tag
20	Factory 4.0	Smart Products	Customize d Products	Regular product productio n	Customize d product production planned but not yet implement ed	Customize d products can be produced but manual work required.	Customize d product production supported by machines but requires manual changeove r	Customize d products can be produced automatica lly based on the demands. System adapts itself automatica lly

21	Factory 4.0	Smart Products	Digital Product-Service Systems	only physical product	maintenance services sold together with product	extended services sold together with product	digital services sold together with the product	digital services available on via web, app or cloud
22	Factory 4.0	Product Design and Development	Product Lifecycle Management	No CAD software	2D CAD software	3D CAD software	PDM (Product Data Management) tools or software	PLM (Product Lifecycle Management) tools or software
23	Factory 4.0	Communication and Connectivity	Digital and Connected Workstations	Paper information on workstation	Centrally accessible Info screens in production	Mobile tablets in production	Digital workstations through screen / industrial pc on workstations	Digital and connected workstations screen / industrial pc on every workstation
24	Factory 4.0	Communication and Connectivity	Internet of Things	No IoT infrastructure	Sensors/actuators in production and Wi-Fi or wired LAN for data transfer	Data to information - make data available for everyone	Cognitive analysis and custom apps to optimize processes	Self-configuration, adjustment and optimization based on data
25	Factory 4.0	Communication and Connectivity	Cyber Physical Systems	No CPS infrastructure	Sensors/actuators in production and Wi-Fi or wired LAN for data transfer	Data to information - make data available for everyone	Cognitive analysis and custom apps to optimize processes	Self-configuration, adjustment and optimization based on data
26	Factory 4.0	Operations	Self-Adapting Manufacturing Systems	No self-adapting systems	Operations can adapt only test plans based on products	Only a few operations can perform self-adapting systems based on product reference	Operations can perform self-adapting systems but still manual work has to be performed	Self-adapting systems are widely used and operations can perform automated changeover without any manual work
27	Logistics 4.0	Transparency	E-Kanban	No Kanban	Bin Kanban	Card Kanban with Kanban Board	E-Kanban used for internal replenishment	E-Kanban connected with external supplier

28	Logistics 4.0	Customers	End-to-end visibility	No production visibility for customers	Production is visible only for internal tracking	Product and process activities including supply chain, production and supplier are visible but only for internal usage	All product activities are available but only some of them visible to customer	All product activities are available and all of them shared with customer
29	Logistics 4.0	Inventory control	Wireless Communication	Only wired communication available	Wireless communications used as pilot applications	Wireless communications are used in whole company but only devices can get access.	Wireless communications are available. Mobile/tablet can access to communications.	Wireless communication widely used in company and standardized data protection systems implemented.
30	Logistics 4.0	Supply chain	Vertical & Horizontal System Integration	No vertical and horizontal system integration	Vertical and horizontal system integration is planned. But no applications available	Vertical and horizontal system integration is applied to specific areas as pilot applications	Well-integrated processes in shop floor while the production floor tightly coordinated. However, there is no high-level business processes such as procurement	Well-integrated processes at the production-floor level while the production floor is tightly coordinated with higher-level business processes such as procurement and quality control
31	Logistics 4.0	Supply chain	Sustainable Supply Chain Design	No consideration of footprint or sustainability	Consideration of sustainability in Supply Chain decisions/design	Consideration of sustainability in Production design	Footprint Measurement in the own value chain	Global Footprint Measurement
32	Logistics 4.0	Supply chain	Collaboration Network Models	No collaboration	Close collaboration with strategic partners	Collaborative Production Networks	Collaborative Cloud Manufacturing Networks	Virtual Enterprise Network

33	Logistics 4.0	Real-time tracking	Smart Sensors	No tracking available	Paper based inventory control provided manually	Some of critical points regular sensors used to track inventories	Smart sensors are used to track real-time inventories.	Smart sensors are available for real-time tracking and decision-making systems are implemented to do the required needs in any case
34	Logistics 4.0	Warehouse and Storage	Automated Storage Systems	Manual storage system	Mechanical placing and retrieving (e.g. forklift)	Mechanized storage system (e.g. with electric drives)	Automated storage system	Automated storage with optimization logic for chaotic storage
35	Logistics 4.0	Automated scheduling	Smart Assistance Systems	No worker assistance	Physical aid systems	Sensor aid systems	Cognitive Aid Systems	Self-learning assistance systems
36	Operator 4.0	Collaboration	Cultural Transformation	The employees have not yet been confronted with the Industry 4.0 culture	The employees were confronted with the Industry 4.0 culture, but they are skeptical about it	The employees are aware that Industry 4.0 culture is necessary for the company	The employees have partly adopted the Industry 4.0 culture	The employees largely adopted the Industry 4.0 culture
37	Operator 4.0	Human Resource 4.0	Training 4.0	No specific trainings	Employees are sent to specific training courses related to the job profile	Employees have a basic knowledge about Industry 4.0 / Smart Manufacturing through training courses	Employees have an advanced knowledge about Industry 4.0 / Smart Manufacturing through training courses	Train the Trainer - internal trainers/experts transfer their knowledge to internal employees
38	Operator 4.0	Governance	Operator Role	Operator = manual work	Operator = work assisted through machines	Operator = work assisted through machines and CAx and NC tools	Operator = cooperative work through man-machine collaboration	Operator = supervisor of work aided by machines in Cyber-Physical Production Systems

39	Operator 4.0	Operator Ergonomics	Automated Material Handling Systems	Manual transport systems	Mechanical transport systems (forklift truck)	Forklift trucks with forklift control system	Track guided forklift trucks	Automated Guided Vehicles (AGV)
40	Operator 4.0	Operator Ergonomics	Collaborative Robots	No use of robotic stations	Worker and robots are strictly separated	Shuttle table with a loading/unloading side (worker) and an operative side (robot)	Use of lightweight robots for collaborative robotics with force limitation	Specific security measures for collaborative robotics (e.g. virtual fence,)
41	Management 4.0	Leadership and organization	Decentralization	No decentralization	Company aware of decentralization but not yet implemented	Decentralization applied to only lower management.	Decentralization applied to selected management levels. Only major decisions cannot be delegated.	Decentralization applied to all management levels and organizations.
42	Management 4.0	Scheduling and maintenance	Predictive Maintenance	No maintenance strategies (reactive repair)	Preventive Maintenance based on experience and historical data	Preventive and Automated Maintenance (System forecast maintenance)	Predictive Maintenance	Predictive and Automated Maintenance
43	Management 4.0	Scheduling and maintenance	Tele-Maintenance	No Tele-Maintenance	Tele Maintenance via smartphone camera	Tele Maintenance via fix installed camera on machine	Remote Maintenance via remote access to the machine control	Augmented Reality to support Tele Maintenance
44	Management 4.0	Scheduling and maintenance	Object Self Service	Customer reorders material, service or spare parts for a sold product	Seller signalizes to customer a probable need to reorder material, service or spare parts	Product signalizes need for reordering of material, services or spare parts to customer	Product signalizes need for reordering of material, services or spare parts to customer and seller	Product reorders automatically material, services or spare parts
45	Management 4.0	Investments	Real-Time Process Control Systems	No real time process control systems	Process systems are manually controlled in specific times	Process systems are manually controlled periodically but pilot applications for real time control systems available.	Process systems are real time controlled in selected areas	Real time process control systems used in whole production and monitoring systems are available

46	Management 4.0	Finance	Material Requirements Planning (MRP)	production planning, scheduling, and inventory control system are not applied.	production planning, scheduling, and inventory control system are tracked manually	production planning, scheduling, and inventory control system tracked manually but pilot applications for MRP.	MRP applied only selected areas.	MRP applied in whole company. Frequently meeting organized to increase applicability
47	Management 4.0	Finance	Manufacturing Resource Planning	No manufacturing resource planning	Manufacturing resource planning is performed only in operation	Manufacturing resource planning performed to all sources only in operation	Effective planning of all resources of a manufacturing such as operational planning in units, financial planning but has no simulation capability to answer "what-if" questions	Effective planning of all resources of a manufacturing such as operational planning in units, financial planning, and has a simulation capability to answer "what-if" questions
48	Management 4.0	Finance	Servitization and Sharing Economy	Customer buys physical product (Ownership)	Customer pays the leasing rate to get ownership	Customer pays a rental rate (no ownership intended)	customer pays for the service	customers share access to products or services with other customers
49	Management 4.0	Data security	Cyber Security	No effort for cyber security	Traditional cyber security effort (firewall, back-up.)	Risk management matrix to analyze risk and to define the right counter-measures	Company is protected against the riskiest cyber security issues	Company exceeds industry standards in cyber security
50	Management 4.0	Intellectual property	Copyrights and Patents	Copyrights, patents and designs are not protected	Copyrights, patents and designs are not protected but pilot applications on going.	Copyrights, patents and designs are protected internally.	Copyrights, patents and designs are protected and can last forever.	Copyrights, patents and designs are protected as well as registered with the government to gain protection.

51	Management 4.0	Business Models 4.0	Digital Lock-in	No Lock-in model	product guarantee ends with the use of not original parts	product guarantee ends with the use of not original parts but there are pilot applications of OEM digital services	suggest customer to use the original OEM digital services	Assure that no other than OEM can offer digital service
52	Management 4.0	Business Models 4.0	Freemium	no after sales service required	Free physical services in order to increase value proposition and competitive advantage	Free basic services (e.g. physical maintenance check) and charged premium services (e.g. change of spare parts)	Free digital services in order to increase value proposition and competitive advantage	Free basic services (e.g. maintenance check) and charged premium services (e.g. product monitoring app)
53	Management 4.0	Standards 4.0	CPS Standards	No standardization	Partial standardization	Physical electro-mechanical standardization	Communication standards	Standardization above industry standards
54	Management 4.0	Innovation Strategy	Open Innovation	Internal product development	Involve supplier for problem solution and idea gathering	Single Open Innovation activities	Participate in Open Innovation platforms to get ideas from outside	Use science fiction to describe and explore implications of futuristic technologies
55	Management 4.0	Innovation Strategy	Strategy 4.0	No I4.0 strategy available	Strategy exists, but is not documented (only in minds of management)	Existing strategy and masterplan for implementation	Industry 4.0 strategy and integration of Industry 4.0 in the overall company strategy	Industry 4.0 Roadmap with defined Masterplan for stepwise implementation

Appendix B: Questionnaire for Case Study

A FRAMEWORK FOR ASSESSING INDUSTRY 4.0 READINESS AND MATURITY OF SMART MANUFACTURING ENTERPRISES

A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey

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Subject: ***A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey.***

Dear Participant:

I am a PhD student at the Faculty of Engineering, Eastern Mediterranean University, Famagusta, North Cyprus, Via Mersin 10, Turkey. For my research, I am examining the ***A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey***.

Industry 4.0 is a vision that describes the industry of the future. The specific potential lies above all in high-flexibility, high-productivity, resource friendly production that makes it possible to manufacture highly individualized products under the economic conditions of mass production. Engineering, production, logistics, service, and marketing are ultimately interconnected in dynamic, real-time-optimized, value-adding cross-enterprise networks. This research aims to investigate the adoption of industry 4.0 technologies in Turkey. A questionnaire has been designed for primary data acquisition. The research will focus on the awareness, knowledge, readiness, willingness to invest, challenges and benefits of Industry 4.0 in Turkey. Finally, based on available data, a growth model will be applied to forecast the adoption of industry 4.0 technologies in Turkey.

I am inviting you to participate in this research study by completing the attached survey form. The following questionnaire will require approximately 15 minutes to complete. Participation is voluntary. Please answer all questions as honestly, as possible. There is no compensation for responding nor is there any known risk. In order to ensure that all information will remain confidential, please do not include your name. Completion and return of the questionnaire will indicate your willingness to participate in this study. **The identity of the participants will not be disclosed, and complete anonymity will be ensured.** Your participation will help us to evaluate current views and practices regarding the adoption of industry 4.0. I appreciate your voluntary participation, comments and opinions, and I am extremely grateful for your time and efforts.

If you require additional information or have questions, please contact me at the email listed below. We will be grateful for your insightful opinions and comments, and valuable time and efforts. Thank you.

Yours Sincerely,

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Participant Debrief Form

Thank you very much for participating in this study titled ***A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey***. Please take a few more minutes to read the following information, which will explain the aims and purpose of the research further. If you have any questions, please feel free to ask the researcher whose contact details are stated below.

Industry 4.0 is a vision that describes the industry of the future. The specific potential lies above all in high-flexibility, high-productivity, resource friendly production that makes it possible to manufacture highly individualized products under the economic conditions of mass production. Engineering, production, logistics, service, and marketing are ultimately interconnected in dynamic, real-time-optimized, value-adding cross-enterprise networks. This research aims to investigate the adoption of industry 4.0 technologies in Turkey. A questionnaire has been designed for primary data acquisition. The research will focus on the awareness, knowledge, readiness, willingness to invest, challenges and benefits of Industry 4.0 in Turkey. Finally, based on available data, a growth model will be applied to forecast the adoption of industry 4.0 technologies in Turkey.

If during the completion of this questionnaire you felt any distress or discomfort and you would like to speak to a professional, please contact the researcher (name, email, phone number) or the research supervisor (name, email, office phone number) with any questions. Once again thank you for your valuable contribution to this research. Your participation is greatly appreciated.

Yours Sincerely,

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The following completion instructions are presented for your convenience and to easily guide you through the survey.

- The survey mainly consists of four parts and an appendix, they are:

  Part 1: Participant Consent Form (PCF) **(Mandatory)**.

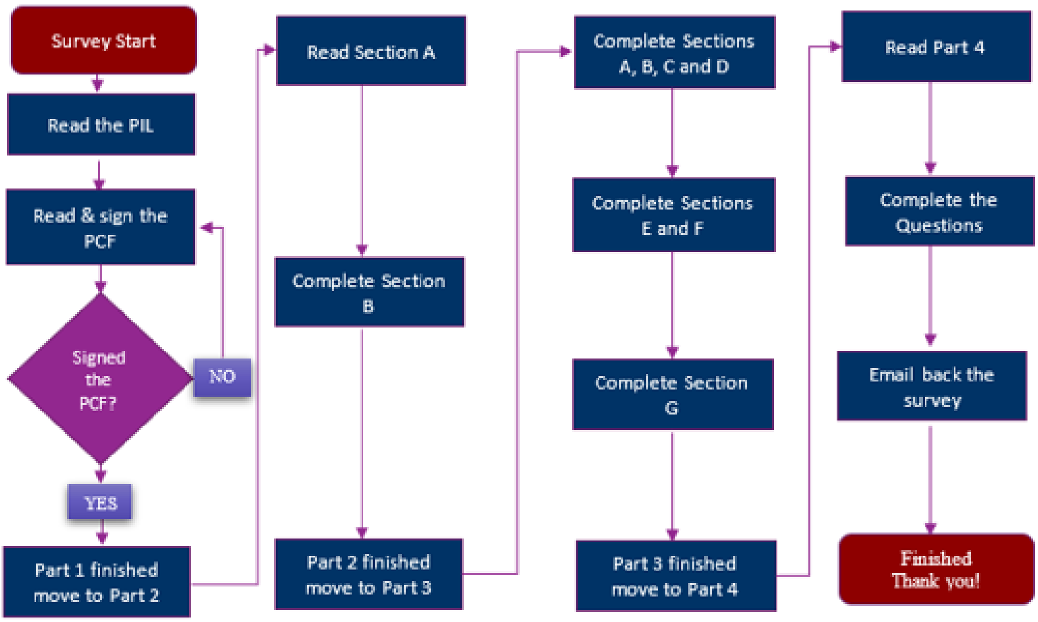
  Part 2: Personal Information (Section A: Optional, Section B: Mandatory)

  Part 3: Questionnaire.

  Part 4: General Questions.

  Appendix: Definition of Key Terms.

- The following flowchart explains the process for completing the survey.



For your participation, you may use this PDF softcopy or kindly print the file and email back scanned copies to cinar.zekimurat@gmail.com.

- Each Part of the Survey contain guiding instruction to smoothly take you through the completion of the specified part.

- In case you would like to add any comment about a certain issue, please include it in the comments box at each section of the survey.

- For your convenience, definition of key terms is included in the appendix.

Part 1 : Participant Consent Form (PCF)

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Title of Study: ***A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey.***

Dear participant,

Please take a few minutes to read the following information on this research carefully before you agree to participate. If at any time you have a question regarding the study, please feel free to ask the researcher who will provide more information.

This study is being conducted by PhD Student Mr. Zeki Murat Cinar under the supervision of Dr. Qasim Zeeshan and Dr. Orhan Korhan. It aims to investigate the *A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey*. The survey should take no more than 15 minutes to complete.

Of course, you are not obliged to participate in this research and are free to refuse to participate. You may also withdraw from the study at any point without giving any reason. In this case, all of your responses will be destroyed and omitted from the research. If you agree to participate in and complete the study, all responses and questionnaires will be treated confidentially. Your name and identifying information will be kept securely and separately from the rest of your questionnaire.

Data will be stored for a maximum of six years after the study. Once the data is analyzed, a report of the findings may be submitted for publication.

To signify your voluntary participation, please complete the consent form below.
CONSENT FORM
Research Title: ***A Framework for Assessing Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises in Turkey.***
Name of Researchers: **Mr. Zeki Murat Cinar, Assoc. Prof. Dr. Qasim Zeeshan, Assoc. Prof. Dr. Orhan Korhan**

Name, Email address & Address: cinar.zekimurat@gmail.com

Please tick the boxes to confirm that you agree to each statement.

1. I confirm that I have read and understood the information sheet for this study and have had the opportunity to ask any questions. ☐

2. I understand that my participation is voluntary and that I may withdraw from the study at any time without explanation. ☐

3. I agree to take part in this study. ☐

Date Signature

Part 2: General Information

Thank you for accepting to participate in this research. This part consists of two sections as following:

Section A: OPTIONAL

By filling the information in this Section, you **agree to disclose** some of this information in the research. However, if you wish, you may fill this section as you see appropriate, and if you decide to keep this information totally **anonymous**, please proceed to **Section B**.

Name:

Email:

Your Company/Organisation Name:

Section B: MANDATORY

Kindly choose the appropriate field for each question of the following.

Region of Your Company/ Organization:	Aegean Region	Black Sea Region	Central Anatolia	Eastern Anatolia	Marmara Region
	Mediterranean Region	South-Eastern Anatolia Region			
Type of Industry sector of your Company/Organization:	Academia & Research	Aerospace, Defense & Security	Agriculture	Automotive	Biomedical Equipment
	Chemicals	Computer, Electronics	Construction Equipment	Electrical Equipment	Engineering & Construction
	Energy, Oil & Gas	Energy, Renewables	Food & Beverages	Furniture & Home Furnishing	Industrial Equipment
	Pharmaceuticals	Rubber & Plastic Products	Textile, Wearing Apparel, Garments, Leather products	Transportation & logistics	Wood, paper products, and printing
	Other Manufacturing				
Enterprise:	Large (500+ employees)	Medium (100 to 499 employees)	Small (10 to 99 employees)	Micro (less than 10 employees)	
	National	Multinational			
Your Job Function/ Business Area:	Production/ Manufacturing	Planning	Research & Development	Supply Chain	Logistics/ Distribution
	Academia	Procurement/ Purchasing	Marketing/ Sales	Human Resource	
	Other Please specify	:________________			
Level of Management /Designation:	Executive	Senior Management	Middle Management	Junior Management	
Years of Experience:	30+ years	21-30 years	11-20 years	6-10 years	1-5 years
Highest Educational Qualification:	Doctoral Degree	Master's Degree	Bachelor's Degree	College Degree	Upper Secondary School

Which of the following systems and technologies are you currently using or intend to use in the near future?

This section is designed to assess the level of awareness, knowledge, readiness and expertise on Industry 4.0 technologies. Please rate the following criteria according to your awareness level by double clicking on the appropriate check box and choosing "Checked" under default value.

	TODAY					IN 5 YEARS				
	Outsid	Beginn	Intermedi	Experien	Top	Outside	Beginner	Intermedia	Experien	Top
Additive Manufacturing (3D	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Augmented Reality	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Autonomous Robotics	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Big Data Analytics (BDA)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cloud Computing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cyber Physical Systems (CPS)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cyber Security	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industrial Internet of Things	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Machine Learning	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Smart Sensors	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Real-Time Process Control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wireless Communication	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Predictive Maintenance	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Vertical & Horizontal System	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Computer Network	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Computer Graphics	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Databases	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Embedded Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Computer Aided Manufacturing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Computer Aided Design (CAD)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Computer Aided Engineering	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Computer Aided Process	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Flexible Manufacturing Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Numerical Control Machines	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Automated Material Handling	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Environmental Control Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bar-coding / Automatic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
RFID Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Material Requirements Planning	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manufacturing Resource	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Agile Manufacturing Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Automated Manufacturing and	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Continuous material flow models	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Plug-in Procedure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Self-Adapting Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MES Integration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Artificial Intelligence	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Customized Products	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Digital Product-Service Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Product Lifecycle Management	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Digital and Connected	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
E-Kanban	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
End-to-end visibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sustainable Supply Chain Design	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Collaboration Network Models	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Smart Assistance Systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Tele-Maintenance	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Real-Time Process Control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Object Self Service	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Servitization and Sharing Economy	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Intellectual Property Protection	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Freemium	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
CPS Standards	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Automated Storage Systems	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐

Comments:

Part 3: Questionnaire

Section A: FACTORY 4.0

This section is designed to assess the level of awareness, knowledge, readiness and expertise on Factory 4.0 technologies. Please rate the following criteria according to your awareness level by double clicking on the appropriate check box and choosing "Checked" under default value.

What proportion of the process equipment and system infrastructure can be controlled through automation?

- ☐ All machines and systems can be controlled completely through automation
- ☐ Most machines and system infrastructures can be controlled through automation
- ☐ Some machines and system infrastructure can be controlled through automation
- ☐ None of the machines can be controlled through automation
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent are machines and operational systems integrated (M2M)?

- ☐ Machines and systems are fully integrated
- ☐ Machines and systems are partially integrated
- ☐ Machines and systems are to some extent able to exchange information between themselves
- ☐ Machines and systems have no machine-to-machine capability
- ☐ Subject not relevant to company
- ☐ Don't know

Are autonomously guided workpieces (e.g. autonomous material handling equipment) used in operations?

- ☐ Autonomously guided workpieces are widely adopted
- ☐ Autonomously guided workpieces are used in selected areas
- ☐ Autonomously guided workpieces are not in use but, there are pilot underway
- ☐ Autonomously guided workpieces are not in use
- ☐ Subject not relevant to company
- ☐ Don't know

Are self-optimizing processes used in manufacturing system?

- ☐ Self-optimizing processes are widely used
- ☐ Self-optimizing processes are used in selected areas
- ☐ Self-optimizing processes are not in use, but there are pilot in more advanced areas of the business
- ☐ Self-optimizing processes are not in use
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent is digital modelling used in operations?

- ☐ Complete digital modelling used for all relevant processes
- ☐ Most processes are using digital modelling
- ☐ Some processes are using digital modelling

- ☐ No digital modelling
- ☐ Subject not relevant to company
- ☐ Don't know

How is operations data collected and in which areas?

- ☐ Comprehensive automated, digital data collection across the entire processes
- ☐ Comprehensive digital data collection in multiple areas
- ☐ The required data is collected digitally in certain areas
- ☐ Data collected manually when required – i.e. sampling for Quality Control
- ☐ Subject not relevant to company
- ☐ Don't know

How much of the operations data collected is used and for what purposes?

- ☐ All data is used not only to optimize processes, but also for decision making
- ☐ Some data is used to control and optimize processes (i.e. predictive maintenance)
- ☐ Some data is used to control processes
- ☐ Data is only used for quality and regulatory purposes
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent are cloud solutions used in data processing?

- ☐ Multiple solutions implemented across the business
- ☐ Plot solutions implemented in some areas of business
- ☐ Initial solutions planned for cloud-based software, data storage and data analysis
- ☐ Cloud solutions not in use
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent are IT technologies used in manufacturing and operations?

- ☐ IT security solutions have been implemented for all relevant areas and are reviewed frequently to ensure compliance
- ☐ Comprehensive IT security solutions have been implemented with plans developed to close any gaps
- ☐ IT security solutions have been partially implemented
- ☐ IT security solutions are planned, but not yet implemented
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent can products be tracked throughout their lifecycle?

- ☐ Products can be tracked along their complete lifecycle
- ☐ Products can be tracked through manufacturing and distribution until they reach the customer DC
- ☐ Products can be tracked as they move between manufacturing and internal distribution sites
- ☐ No or limited product tracking
- ☐ Subject not relevant to company
- ☐ Don't know

How often do you conduct a cost / benefit analysis for Industry 4.0 investment?

- ☐ Quarterly cost / benefit analysis of Industry 4.0 investment
- ☐ Annual cost / Benefit analysis of Industry 4.0 investment
- ☐ No ongoing review of cost / Benefit analysis for Industry 4.0 investment
- ☐ No measurable Industry 4.0 investments yet
- ☐ Subject not relevant to company
- ☐ Don't know

Thank you for completing Section A. Please Proceed to Section B.
Comments:

Section B: LOGISTICS 4.0

This section is designed to assess the company manufacturing and operations in the light of Logistics 4.0 technologies. Please rate the following criteria according to your company/organisation manufacturing and operations in each one.

To what extent is real-time data management used for inventory control?

- ☐ Real-time database which is updated by smart devices
- ☐ Computer database used with smart devices updating inventory levels
- ☐ Computer database is used which is manually updated with inventory levels
- ☐ Some data available for evaluation of inventory levels
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent is the current supply chain integrated?

- ☐ Fully integrated systems with suppliers/customers for appropriate processes (for example real-time integrated planning)
- ☐ Data transfer between key strategic supplies/customers (for example customer inventory levels)
- ☐ Basic communication and data sharing where required with supplier and customers
- ☐ Ad hoc 'reactive communication with suppliers and customers
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent does your supply chain an end-to-end visibility?

- ☐ Site location, capacity, inventory and operations are visible in real time throughout supply chain and used for monitoring.
- ☐ Site location, capacity, inventory and operations are visible throughout supply chain
- ☐ Site location, capacity, inventory and operations are visible between first tier suppliers and customers
- ☐ No integration with suppliers or customers
- ☐ Subject not relevant to company
- ☐ Don't know

Which of the following statements best describes the agility of your supply chain?

- ☐ Intermediate responses to changes in market environment and individual customer requirements
- ☐ Moderate response to changes in market environment and individual customer requirements
- ☐ Moderate response to market changes and general customer requirements shifts
- ☐ Slow response to market changes
- ☐ Subject not relevant to company
- ☐ Don't know

Which of the following statements best describes your lead times?

- ☐ Differentiated stocking policies and lead times to meet Manufacture-To-Order efficiency
- ☐ Some improvements have been implemented to reduce lead times on key materials
- ☐ Improvements have been identified to reduce lead times for some materials
- ☐ Long materials lead time resulting in high inventory levels
- ☐ Subject not relevant to company
- ☐ Don't know

Thank you for completing Section B. Please Proceed to Section C.

Section C: OPERATOR 4.0

This section is designed to assess the company manufacturing and operations in the light of Operator 4.0 technologies. Please rate the following criteria according to your company/organisation manufacturing and operations in each one.

To what extent are employees equipped with relevant skills for Industry 4.0?

- ☐ All across the business, cutting edge digital and analytical skills are prevalent
- ☐ Most areas of the business have well developed digital and data analysis capacity
- ☐ Technology focused areas of the business have employees with some digital skills
- ☐ Employees have little or no experience with digital technologies
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent do departments collaborate with each other?

- ☐ Departments are open to cross-company collaboration to drive improvements
- ☐ Departments are open to cross-functional collaboration
- ☐ There is limited interaction between departments (i.e. S&OP[1] process)
- ☐ The business operates in functional silos
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent does the leadership team support Industry 4.0?

- ☐ Widespread support for the Industry 4.0 within both the leadership team and across the wider business
- ☐ Leadership team recognizes the financial benefits to be obtained through Industry 4.0 and is developing plants to invest
- ☐ Leadership team is investigating potential Industry 4.0 benefits
- ☐ Leadership team does not recognize the value of the Industry 4.0 investments
- ☐ Subject not relevant to company
- ☐ Don't know

Thank you for completing Section C. Please Proceed to Section D.

Section D: MANAGEMENT 4.0

This section is designed to assess the company manufacturing and operations in the light of Management 4.0 technologies. Please rate the following criteria according to your company/organisation manufacturing and operations in each one.

To what extent has Industry 4.0 strategy been implemented by the company?

- ☐ Industry 4.0 strategy has been implemented across the business
- ☐ Industry 4.0 strategy has been communicated to the business and is widely understood
- ☐ Industry 4.0 is included in the business strategy
- ☐ Industry 4.0 is recognized at departmental level but is not integrated into the strategy
- ☐ Subject not relevant to company
- ☐ Don't know

To what extent has Industry 4.0 been measured by the company?

- ☐ Business metrics and personal development plans are focused around Industry 4.0 objectives
- ☐ Industry 4.0 metrics are widely understood in the business and used in monthly reporting
- ☐ Structured sets of business metrics exist with some measurement of Industry 4.0 drivers
- ☐ KPI's[2] are not focused around Industry 4.0
- ☐ Subject not relevant to company
- ☐ Don't know

Which of the following statements best describes the scheduling and maintenance trigger?

- ☐ Machines are generally self-diagnosing, and maintenance schedule adjusts itself based on real-time data inputs from the
- ☐ Some machines are self-diagnosing, automatically passing information to the maintenance scheduling system
- ☐ Some machines alert operators of a performance issue which enables them to manually schedule a maintenance task
- ☐ Equipment is manually maintained in line with the maintenance schedule
- ☐ Subject not relevant to company
- ☐ Don't know

Where do you see your company in handling the legal risks associated with Industry 4.0?
☐ New risks identified and assessed the changing risk profile and we have procedures in place to mitigate these
☐ New risks identified and/or assessed and limited mitigations put in place
☐ New risks identified and/or assessed but no mitigations planned
☐ New risks not identified or assessed
☐ Subject not relevant to company
☐ Don't know

What is your current level of data protection management?
☐ Conducted a recent GDPR[1] audit and are confident of compliance including in the light of Industry 4.0
☐ Good understanding with robust policies and procedures but haven't updated for EU General Data Protection Regulation
☐ Have internal policies but do not ensure compliance in engagement with suppliers/customers
☐ Have no data protection policies or procedures
☐ Subject not relevant to company
☐ Don't know

Which of the following statements best describes your intellectual property?
☐ Intellectual property in products and services identified and assessments made as to registrations/contractual rights required.
☐ Intellectual property in products and services identified and assessments planned as to registrations/contractual rights
☐ Awareness of intellectual property in new products and services but no legal protections identified and applied for
☐ Intellectual property in new products and services in not identified or protected
☐ Subject not relevant to company
☐ Don't know

If you think that **all** these technologies will make **No impact** on your business, please tick the box. Then, please proceed to Part 4. ☐

Thank you for completing Section D. Please Proceed to Section E.

Section E: Understanding the Benefits.

This section is designed to understand seen or expected benefits in your organisation from adopting industry 4.0 technologies. This information is helpful to understand the advantages of the fourth industrial revolution in different businesses. Please rate the following criteria according to your seen or expected observation.

	Very Low	Low	Moderate	High	Very High
Increased Productivity	☐	☐	☐	☐	☐
Increased Flexibility	☐	☐	☐	☐	☐
Developed Customers' Satisfaction	☐	☐	☐	☐	☐
Expanding Business into New Markets	☐	☐	☐	☐	☐
Improved Product Quality	☐	☐	☐	☐	☐
Increase in Customized/Personalized Products	☐	☐	☐	☐	☐
Real-time Data Collection and Faster Decision Making	☐	☐	☐	☐	☐
Reduced Business Costs	☐	☐	☐	☐	☐
Improved Business Turnover	☐	☐	☐	☐	☐
Enhanced Employees' Productivity	☐	☐	☐	☐	☐

If you think there are other benefits and not mentioned above, please mention them in the comments.

Comments:

If you see or expect that all industry 4.0 technologies **are not or will not** benefit your business on all the previous criteria, please check the next box. ☐

If you have seen or expect any benefits other than the above mentioned, please share your observations in the comments box below. Then you kindly move to Part 4.

Thank you for completing Section E. Please proceed to Section F below.

Section F: Assessing the Challenges and Constraints.

This section is designed to highlight the challenges and constraints of adopting industry 4.0 technologies. The following criteria are classified into economical, technological, organisational, and **human factors** of concern. Please rank them in light with your current business position.

	Very Low	Low	Moderate	High	Very High
Economic Factors	☐	☐	☐	☐	☐
Unclear cost-benefit-ratio	☐	☐	☐	☐	☐
Return on Investment	☐	☐	☐	☐	☐
Insufficient Funds	☐	☐	☐	☐	☐
Other Investment Priorities	☐	☐	☐	☐	☐
Available resources for realization	☐	☐	☐	☐	☐
Technological Factors	☐	☐	☐	☐	☐
Maturity of required technologies	☐	☐	☐	☐	☐
Data Storage Capability	☐	☐	☐	☐	☐
Network Capability	☐	☐	☐	☐	☐
Data & Intelligent System Security	☐	☐	☐	☐	☐
Reliability of Technology	☐	☐	☐	☐	☐
Digital Regulations, Standards	☐	☐	☐	☐	☐
Utilization of customer data	☐	☐	☐	☐	☐
Organisational Factors	☐	☐	☐	☐	☐
Organisational Infrastructure	☐	☐	☐	☐	☐
Decentralization of processes	☐	☐	☐	☐	☐
Qualification/ Competence of workforce	☐	☐	☐	☐	☐
Awareness at Top Management Level	☐	☐	☐	☐	☐
Autonomy of employees	☐	☐	☐	☐	☐
Willingness of leaders/Commitment from Executive	☐	☐	☐	☐	☐
Openness of employees to new technology	☐	☐	☐	☐	☐
Costumer's Digital media competence	☐	☐	☐	☐	☐
Knowledge Sharing	☐	☐	☐	☐	☐
Open-innovation & cross company collaboration	☐	☐	☐	☐	☐

If you think there are other significant factors of concerns, kindly share it in the comment box below.

Section G: **Standards.**

Which of the following Industry 4.0 Standards you are aware?	◯ IEC 62890 - Life-cycle management	◯ IEC 61987 - Industrial-process measurement and control	◯ IEC 6130/ISO 13584 - Industrial automation systems and integration	◯ IEC 62714 - Automation Mark-up Language	◯ IEC 62264 - Enterprise-control system integration
	◯ IEC 61512 - Batch control	◯ IEC 61360 - Classification and product description	◯ IEC 62541 - Machine to machine communication	◯ IEC 61784 - Industrial communicatio n networks	◯ IEC/TR 62794 - Reference model for the digital factory
	◯ VDMA 24582 - Condition monitoring	◯ IEC 61804 - Function blocks for process control / electronic device description language	◯ IEC 62453 - Field device tool (FDT) interface specification	◯ IEC/ISO 20140 - Energy Efficiency	◯ IEC 62443 - Network and system Security
	◯ SPARQL - RIF/SRWL - RDF(S) – OWL - W3C Semantic Web stack	◯ ISO/IEC 27000 - Information security management systems	◯ IEC 61511 - Functional safety	◯ IEC 62061 / ISO 13849 ISO 13849 - Safety of machinery	
Which of the following Industry 4.0 Standards you are using in your company?	◯ IEC 62890 - Life-cycle management	◯ IEC 61987 - Industrial-process measurement and control	◯ IEC 6130/ISO 13584 - Industrial automation systems and integration	◯ IEC 62714 - Automation Mark-up Language	◯ IEC 62264 - Enterprise-control system integration
	◯ IEC 61512 - Batch control	◯ IEC 61360 - Classification and product description	◯ IEC 62541 - Machine to machine communication	◯ IEC 61784 - Industrial communicatio n networks	◯ IEC/TR 62794 - Reference model for the digital factory
	◯ VDMA 24582 - Condition monitoring	◯ IEC 61804 - Function blocks for process control / electronic device description language	◯ IEC 62453 - Field device tool (FDT) interface specification	◯ IEC/ISO 20140 - Energy Efficiency	◯ IEC 62443 - Network and system Security
	◯ SPARQL - RIF/SRWL - RDF(S) – OWL - W3C Semantic Web stack	◯ ISO/IEC 27000 - Information security management systems	◯ IEC 61511 - Functional safety	◯ IEC 62061 / ISO 13849 ISO 13849 - Safety of machinery	

Thank you very much for your time and efforts. Please answer the next final part.

Part 4: General Questions

This part is designed to understand your view on Industry 4.0. Kindly answer the following questions, and if you have any comments, you may leave it in the comment box below.

How do you see your engineering & business operations in the future in light with adopting industry 4.0 technologies?

Which area(s) of your engineering & business do you think/anticipate will benefit mostly from the adoption of industry 4.0 technologies (e.g. Logistics, Production, Sales, etc.)? and how would you describe the change?

What are the economical, technological and organizational challenges and constraints faced by your company/organization in adopting industry 4.0 technologies?

Have you initiated any plans to overcome the aforementioned challenges and constraints? If yes, could you please clarify the nature of these plans?

If you have not initiated any plans, what factors are concerning your engineering & business from overcoming these challenges?

Comments Box:

Thank you very much for your efforts, I am very grateful for your contribution. Kindly email back the completed survey to cinar.zekimurat@gmail.com .

Appendix: Definition of Key Terms

Industry 4.0: Industry 4.0 or the fourth industrial revolution is a strategic project initiated in 2011 by the German government to create smart factories in which manufacturing technologies such as CPS, Cloud Computing and IoT are used to upgrade manufacturing systems to be able to monitor physical processes and make real-time smart decisions in collaboration with humans, machines and sensors (Lee, Bagheri and Kao, 2015).

Industry 4.0 – The term Industry 4.0 stands for the fourth industrial revolution, a new level of organizing and controlling the entire value chain across product lifecycles. This cycle focuses on increasingly personalized customer wishes and extends from the concept to the order, development, production, and shipping of a product to the end customer and ultimately to its recycling, including all associated services.

3D printing: A technology that produces solid objects from digital designs by building up multiple layers of plastic, resin, or other materials in a precisely determined shape (Bono, 2016).

Additive Manufacturing: is the industrial version of 3D printing. It is used to make niche items like medical implants, and to produce plastic prototypes for designers and engineers (La Monica, 2018).

Augmented Reality: A technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view. sensors (Oxford Dictionaries | English, 2018).

The real-time use of information in the form of text, graphics, audio and other virtual enhancements integrated with real-world objects. It is this "real world" element that differentiates AR from virtual reality. AR integrates and adds value to the user's interaction with the real world, versus a simulation (Gartner).

Autonomous Robots: Autonomous robots are robots that (I) can operate various tasks without the involvement of humans, (II) collect information about its nearby environment and use this information to navigate itself to reach the desired destination, (III) work for an extended period without human guidance or intervention, and (IV) move around safely in its environment while performing its assigned task without posing threat to human life, surrounding environment or itself (From et al., 2014).

Big Data: Big data refers to datasets that are too large or complex to analyze with conventional data processing procedures or methods and are subject to rapid, continuous change. Big data inverts IT priorities: Since the data is too big, the programs must now become flexible and agile. (Dumbill, 2012).

Big Data Analytics (BDA): the process of examining large data sets containing a variety of data types to uncover hidden patterns, unknown correlations, market trends, customer preferences, and other useful information (NGDATA, 2018).

Cloud: The cloud is not a single computer but a virtual "computing cloud" consisting of many interconnected computers. Users do not need to be on site to access cloud-based computers.

Cloud computing: Cloud computing refers to the provision of IT infrastructure in the form of a cloud and IT services such as data storage, data analytics, and software. This saves users the trouble of purchasing and installing costly server solutions in their own companies. It is a general term that refers to delivering computational services through visualized and scalable resources over the internet (Zhong et al., 2017).

Cyber-physical systems: CPS link the physical and virtual worlds by communicating through a data infrastructure, the Internet of Things. They are the framework that make it possible to generate a virtual model of real production, analyse all the data streams that arise from sensors and other IT systems, and map their interrelationships. CPS is a mechanism through which physical objects and software are closely intertwined, enabling different components to interact with each other in a myriad of ways to exchange information (Zhong et al., 2017).

Cybersecurity: is the body of technologies, processes and practices designed to protect networks, computers, programs and data from attack, damage or unauthorized access (Techtarget.com, 2018).

Data analytics: Data analytics describes the process of analyzing a company's big data and finding useful interrelationships that support the company's activities. Given the enormous volumes of data in businesses today, data can only yield an added value if it can be placed in context and consolidated under larger categories.

Data-driven services: Data-driven services as defined here include tele maintenance; optimized resource consumption of machinery; availability, performance, and quality enhancements through optimized parameter settings; etc. The objective of data driven services is to align future business models and enhance the benefit to the customer. The after-sales and services business will be based more and more on the evaluation and analysis of

collected data and rely on enterprise-wide integration. The physical products themselves must be equipped with physical IT so they can send, receive, or process the information needed for the operational processes. This means they have a physical and digital component, which in turn are the basis for digitized services in the usage phase of the products.

Digital modelling: A digital model is composed of product-related data supplemented by transaction data, geopositioning data, and other data.

ERP systems: ERP systems offer integrated software solutions for administering, planning, and controlling a company's value-adding processes, thereby providing the foundation for information processing in the company. Today's ERP systems focus on extending functionalities by integrating various functionally specialized systems through advanced planning and scheduling (APS).

Horizontal integration: Horizontal integration in production and automation technology describes the consolidation of various IT systems into an end-to-end solution. It involves the various process steps of production and corporate planning between which material, energy, and information flows. Horizontal integration takes place both within a company and across various companies. The smart factory constantly adapts to new circumstances (such as the order volume or availability of materials) and automatically optimizes its production processes. It does this through integration with suppliers and customers in the value chain.

Industrial Internet of Things (IoT): refers to an information network of physical objects such as electronic sensors, machines, vehicles, buildings and other objects that allows the connection and interaction between these objects to exchange and collect data (Xia et al., 2012).

Information and communications technology (ICT): Information and communications technology refers to all technical devices and systems that can digitize, process, store, and transmit information of any kind.

M2M – Machine-to-machine communications: M2M stands for the automated exchange of information among technical systems or between systems and a central unit. Typical applications include remote monitoring and control. M2M links information and communications technology and forms the Internet of Things.

MES: A manufacturing execution system (MES) constitutes the process-oriented operating level of a multilayer production management system. It is directly linked to the process automation systems. MES, in contrast to ERP systems, features integrated APS logic, which allows more precise and detailed fine-tuning and control as well as better real-time capability.

Predictive maintenance: Predictive maintenance systems are designed to detect machine errors such as interruptions or outages before they happen. The aim is to prevents errors through maintenance and proactive repairs.

Rapid prototyping: A group of techniques used to quickly create a model of a physical part or assembly using three-dimensional computer aided design data. Construction of the part or assembly is usually done using 3D printing or "additive layer manufacturing" technology

RFID: Refers to an automated data collection technology that uses radio frequency waves to transfer data between a reader and a tag to identify, track and locate the tagged item (Gartner). Radio frequency identification can be used for monitoring, quality control, automatic adaptation of the production process, and to identify and share information on an item itself and its environment.

SCM system: Supply chain management systems create cross-enterprise transparency relating to needs, capacities, and inventory along the value chain to support individual companies in their decision-making processes or operational workflows in real time.

Smart factory: Smart factory refers to an intelligent, interconnected factory. Successful implementation of Industry 4.0 enables distributed, highly automated production. Unlike in traditional production, smart workpieces will control and monitor the production process and, in the final expansion

phase, guide themselves autonomously through production. This happens in the environment of the smart factory. The smart factory is a production environment in which the production systems and logistics systems largely organize themselves without human intervention. The smart factory relies on cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things. Industry 4.0 also involves digital modelling through the smart gathering, storage, and processing of data. In this way, the smart factory concept ensures that information is delivered and resources are used more efficiently. This requires the real-time, cross-enterprise collaboration between production systems, information systems, and people. These integrated systems produce huge amounts of data that are processed, analyzed, and integrated into decision-making models.

Smart operations: Smart operations refer to the horizontal and vertical integration of the company, which enables flexible production planning and control. One hallmark of Industry 4.0 is the enterprise-wide and cross-enterprise integration of the physical and virtual worlds. The advent of digitization and the plethora of data it has brought to production and logistics have made it possible to introduce what are in some cases entirely new forms and approaches to production planning systems (PPS) and supply chain management (SCM). The technical requirements in production and production planning necessary to realize the self-controlling workpiece are known as smart operations.

Smart products: Smart products are physical objects equipped with ICT so they are uniquely identifiable and can interact with their environment. They use sensor technology to record their environment and their own status and offer various add-on functionalities in operation. Smart products have information about their own production process and can gather and transmit data during the manufacturing and usage phase. This makes it possible to obtain a digital model of the smart factory and offer data-driven services to customers during the usage phase.

Smart products are a vital component of a unified "smart factory" concept facilitating automated, flexible, efficient production. Physical products are equipped with ICT components (sensors, RFID, communications interface, etc.) to collect data on their environment and their own status. Only when products gather data, know their way through production, and communicate with the higher-level systems can production processes be improved and guided autonomously and in real time. It also becomes possible to monitor and optimize the status of the individual products. This has potential applications beyond production alone. Using smart products during the usage phase makes new services possible in the first place – through communications between customers and manufacturers, for example.

Smart services: Smart services are packages of products and services individually configured over the Internet (acatech, 2014). The services include predictive remote services and new business models such as the trade in production capacities and production data.

Tele maintenance: Tele maintenance refers to computer-controlled remote maintenance of machinery and machine parameters.

Vertical integration: Vertical integration in production and automation technology refers to the integration of various IT systems and various hierarchical levels of production and corporate planning into a single end-to-end solution. Examples of such hierarchical levels include the actor and sensor level, the control level, or the production control level. People, machinery, and resources are digitally modelled in the smart factory, communicating with one another through cyber-physical systems (CPS).

Vertical & Horizontal System Integration: Integrating manufacturing systems vertically and horizontally across the value chain achieving end-to-end digital engineering.

Virtual reality: Provides a computer-generated 3D environment that surrounds a user and responds to that individual's actions in a natural way, usually through immersive head-mounted displays and head tracking (Gartner).

Appendix C: Case Study Results

No	I. Level Dimension	II. Level Dimension	Firm I4.0 score	Theor. Max Level	Firm Target Level	Importance for your firm [1-5]	Firm Gap to target	Weight Gap
1	Factory 4.0	Automation	3.47	5.00	3.97	4.37	0.50	0.44
2	Factory 4.0	Autonomous workplace	3.33	5.00	3.70	4.03	0.37	0.30
3	Factory 4.0	Autonomous workplace	2.53	5.00	2.87	3.30	0.33	0.22
4	Factory 4.0	Autonomous workplace	2.77	5.00	3.07	3.70	0.30	0.22
5	Factory 4.0	Big Data Analytics	2.43	5.00	2.83	3.57	0.40	0.29
7	Factory 4.0	Big Data Analytics	3.53	5.00	3.77	4.27	0.23	0.20
6	Factory 4.0	Big Data Analytics	2.63	5.00	3.00	3.73	0.37	0.27
8	Factory 4.0	Cloud Computing	2.70	5.00	2.87	3.37	0.17	0.11
9	Factory 4.0	Communication and Connectivity	2.40	5.00	2.93	3.33	0.53	0.36
10	Factory 4.0	Cyber Security	3.70	5.00	4.13	4.33	0.43	0.38

11	Factory 4.0	Data-driven services	2.40	5.00	2.73	3.27	0.33	0.22
12	Factory 4.0	Data-driven services	3.00	5.00	3.53	3.87	0.53	0.41
13	Factory 4.0	Data-driven services	2.97	5.00	3.40	3.73	0.43	0.32
14	Factory 4.0	Decision Support Systems	3.70	5.00	3.97	4.27	0.27	0.23
15	Factory 4.0	Additive Manufacturing	1.67	5.00	2.00	2.43	0.33	0.16
16	Factory 4.0	Augmented Reality	1.23	5.00	1.57	2.00	0.33	0.13
17	Factory 4.0	Digital Twin	1.17	5.00	1.43	1.73	0.27	0.09
18	Factory 4.0	Digital Twin	2.63	5.00	2.90	3.20	0.27	0.17
19	Factory 4.0	Digital Twin	2.40	5.00	2.67	3.00	0.27	0.16
20	Factory 4.0	M2M	2.37	5.00	2.70	3.07	0.33	0.20
21	Factory 4.0	Machine Learning	1.40	5.00	1.73	2.20	0.33	0.15
22	Factory 4.0	Scheduling and Maintenance	2.53	5.00	2.70	3.33	0.17	0.11
23	Factory 4.0	Scheduling and Maintenance	1.87	5.00	2.07	2.47	0.20	0.10

24	Factory 4.0	Scheduling and Maintenance	2.70	5.00	2.93	3.33	0.23	0.16
25	Factory 4.0	Operations	1.80	5.00	2.20	2.63	0.40	0.21
26	Factory 4.0	Optimization	2.83	5.00	3.27	3.53	0.43	0.31
27	Factory 4.0	Product Design and Development	3.30	5.00	3.60	4.03	0.30	0.24
28	Factory 4.0	Real-Time Work Virtualization	3.13	5.00	3.27	3.77	0.13	0.10
29	Factory 4.0	Data Driven Services	1.87	5.00	2.17	2.70	0.30	0.16
30	Factory 4.0	Service	3.67	5.00	3.80	3.93	0.13	0.10
31	Factory 4.0	Simulation	2.60	5.00	2.97	3.30	0.37	0.24
32	Factory 4.0	Smart Products	3.23	5.00	3.30	3.53	0.07	0.05
33	Factory 4.0	Smart Products	3.13	5.00	3.40	3.67	0.27	0.20
34	Factory 4.0	Technology Integration	3.17	5.00	3.37	3.63	0.20	0.15
35	Factory 4.0	Technology Integration	2.53	5.00	2.83	3.07	0.30	0.18
36	Factory 4.0	Technology Integration	2.80	5.00	3.00	3.13	0.20	0.13
37	Factory 4.0	Traceability (MES) Integration	3.27	5.00	3.33	3.50	0.07	0.05
38	Factory 4.0	KPI Tracking	2.17	5.00	2.40	2.93	0.23	0.14
39	Factory 4.0	Smart Grid	1.37	5.00	1.60	2.00	0.23	0.09

No	I. Level Dimension	II. Level Dimension	Firm I4.0 score	Theor. Max Level	Firm Target Level	Importance for your firm [1-5]	Firm Gap to target	Weight Gap
40	Logistics 4.0	Big Data Analytics	2.93	5.00	3.23	3.80	0.30	0.23
41	Logistics 4.0	End-to-end visibility	2.70	5.00	2.87	3.20	0.17	0.11
42	Logistics 4.0	Flexibility	3.13	5.00	3.37	3.67	0.23	0.17
43	Logistics 4.0	Work-data visualization	2.60	5.00	2.93	3.33	0.33	0.22
44	Logistics 4.0	Lean Logistics	2.97	5.00	3.37	3.70	0.40	0.30
45	Logistics 4.0	Real-Time Work Virtualization	2.23	5.00	2.43	2.70	0.20	0.11
46	Logistics 4.0	Efficient Resource Management	3.07	5.00	3.23	3.60	0.17	0.12
47	Logistics 4.0	Supply chain	2.17	5.00	2.53	2.87	0.37	0.21
48	Logistics 4.0	Supply chain	2.47	5.00	2.63	3.03	0.17	0.10
49	Logistics 4.0	Transparency	2.60	5.00	2.90	3.07	0.30	0.18
50	Logistics 4.0	Smart Transport	2.77	5.00	2.93	3.40	0.17	0.11
51	Logistics 4.0	Warehouse and Storage	2.23	5.00	2.33	2.67	0.10	0.05

No	I. Level Dimension	II. Level Dimension	Firm I4.0 score	Theor. Max Level	Firm Target Level	Importance for your firm [1-5]	Firm Gap to target	Weight Gap
52	Management 4.0	Lean Manufacturing System	3.33	5.00	3.60	3.93	0.27	0.21
53	Management 4.0	Business Models 4.0	2.23	5.00	2.53	2.70	0.30	0.16
54	Management 4.0	Business Models 4.0	1.80	5.00	1.90	2.07	0.10	0.04
55	Management 4.0	Business Models 4.0	2.00	5.00	2.17	2.30	0.17	0.08
56	Management 4.0	Business Models 4.0	2.60	5.00	2.70	2.90	0.10	0.06
57	Management 4.0	Business Models 4.0	2.23	5.00	2.37	2.47	0.13	0.07
58	Management 4.0	Collaboration	2.40	5.00	2.70	3.03	0.30	0.18
59	Management 4.0	Cyber Security	3.33	5.00	3.60	3.90	0.27	0.21
60	Management 4.0	Data Protection	3.27	5.00	3.47	3.83	0.20	0.15
61	Management 4.0	Governance	2.30	5.00	2.77	3.20	0.47	0.30
62	Management 4.0	I4.0 Investment	2.23	5.00	2.67	3.07	0.43	0.27
63	Management 4.0	Innovation Strategy	1.70	5.00	2.07	2.40	0.37	0.18
64	Management 4.0	Innovation Strategy	2.43	5.00	2.77	3.20	0.33	0.21
65	Management 4.0	Intellectual property	3.53	5.00	3.80	4.03	0.27	0.22
66	Management 4.0	Intellectual Property	3.13	5.00	3.40	3.70	0.27	0.20
67	Management 4.0	I4.0 Investment	2.30	5.00	2.77	3.27	0.47	0.30
68	Management 4.0	Leadership and organization	2.90	5.00	3.20	3.50	0.30	0.21
69	Management 4.0	Object Self Service	2.43	5.00	2.67	2.90	0.23	0.14
70	Management 4.0	Standards 4.0	2.67	5.00	2.90	3.33	0.23	0.16
71	Management 4.0	Strategy 4.0	2.43	5.00	2.90	3.40	0.47	0.32
74	Management 4.0	Strategy 4.0	2.47	5.00	2.73	3.17	0.27	0.17

No	I. Level Dimension	II. Level Dimension	Firm I4.0 score	Theor. Max Level	Firm Target Level	Importance for your firm [1-5]	Firm Gap to target	Weight Gap
72	Operator 4.0	Cognitive Ergonomics	2.30	5.00	2.67	2.90	0.37	0.21
73	Operator 4.0	Cognitive Ergonomics	3.00	5.00	3.30	3.70	0.30	0.22
74	Operator 4.0	Collaboration	3.67	5.00	3.97	4.27	0.30	0.26
75	Operator 4.0	Culture	2.27	5.00	2.60	3.20	0.33	0.21
76	Operator 4.0	Governance	2.60	5.00	3.10	3.53	0.50	0.35
77	Operator 4.0	Human - Machine Interaction	3.77	5.00	4.00	4.20	0.23	0.20
78	Operator 4.0	Human - Machine Interaction	3.17	5.00	3.50	3.93	0.33	0.26
79	Operator 4.0	Human Resources 4.0	2.20	5.00	2.50	3.13	0.30	0.19
80	Operator 4.0	Operator Skills	2.07	5.00	2.43	2.90	0.37	0.21
81	Operator 4.0	Organizational Ergonomics	2.40	5.00	2.83	3.13	0.43	0.27
82	Operator 4.0	Physical Ergonomics	2.73	5.00	2.97	3.47	0.23	0.16
83	Operator 4.0	Smart Work Sequencing	3.10	5.00	3.30	3.60	0.20	0.14
84	Operator 4.0	Workload Management System	2.87	5.00	3.17	3.63	0.30	0.22

Appendix D: Questionnaire for I4.0 Knowledge and Awareness in Turkey

INDUSTRY 4.0 SURVEY

Awareness and Knowledge of Industry 4.0 in Turkey

ZEKI MURAT CINAR
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DEPARTMENT OF MECHANICAL ENGINEERING
EASTERN MEDITERRANEAN UNIVERSITY
FAMAGUSTA, NORTH CYPRUS (TRNC)
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Tel: +90 392 630 1210
Fax: +90 392 365 3715
Web: https://me1.emu.edu.tr/en

Subject: ***Investigating the Awareness and Knowledge of Industry 4.0 in Turkey***

Dear Participant:

I am a PhD student at the Faculty of Engineering, Eastern Mediterranean University, Famagusta, North Cyprus, Via Mersin 10, Turkey. For my research, I am examining the ***Awareness and Knowledge of Industry 4.0 in Turkey***.

Industry 4.0 is a vision that describes the industry of the future. The specific potential lies above all in high-flexibility, high-productivity, resource friendly production that makes it possible to manufacture highly individualized products under the economic conditions of mass production. Engineering, production, logistics, service, and marketing are ultimately interconnected in dynamic, real-time-optimized, value-adding cross-enterprise networks. This research aims to investigate the adoption of industry 4.0 technologies in Turkey. A questionnaire has been design for primary data acquisition. The research will focus on the awareness, knowledge, readiness, willingness to invest, challenges and benefits of Industry 4.0 in Turkey. Finally, based on available data, a growth model will be applied to forecast the adoption of industry 4.0 technologies in Turkey.

I am inviting you to participate in this research study by completing the attached survey form. The following questionnaire will require approximately 15 minutes to complete. Participation is voluntary. Please answer all questions as honestly, as possible. There is no compensation for responding nor is there any known risk. In order to ensure that all information will remain confidential, please do not include your name. Completion and return of the questionnaire will indicate your willingness to participate in this study. **The identity of the participants will not be disclosed, and complete anonymity will be ensured.** Your participation will help us to evaluate current views and practices regarding the adoption of industry 4.0. I appreciate your voluntary participation, comments and opinions, and I am extremely grateful for your time and efforts.

If you require additional information or have questions, please contact me at the email listed below. We will be grateful for your insightful opinions and comments, and valuable time and efforts. Thank you.

Yours Sincerely,

Zeki Murat Cinar
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Participant Debrief Form

Thank you very much for participating in this study titled ***Awareness and Knowledge of Industry 4.0 in Turkey***. Please take a few more minutes to read the following information, which will explain the aims and purpose of the research further. If you have any questions, please feel free to ask the researcher whose contact details are stated below.

Industry 4.0 is a vision that describes the industry of the future. The specific potential lies above all in high-flexibility, high-productivity, resource friendly production that makes it possible to manufacture highly individualized products under the economic conditions of mass production. Engineering, production, logistics, service, and marketing are ultimately interconnected in dynamic, real-time-optimized, value-adding cross-enterprise networks. This research aims to investigate the adoption of industry 4.0 technologies in Turkey. A questionnaire has been design for primary data acquisition. The research will focus on the awareness, knowledge, readiness, willingness to invest, challenges and benefits of Industry 4.0 in Turkey. Finally, based on available data, a growth model will be applied to forecast the adoption of industry 4.0 technologies in Turkey.

If during the completion of this questionnaire you felt any distress or discomfort and you would like to speak to a professional, please contact the researcher (name, email, phone number) or the research supervisor (name, email, office phone number) with any questions. Once again thank you for your valuable contribution to this research. Your participation is greatly appreciated.

Yours Sincerely,

Zeki Murat Cinar
Doctoral Candidate
Department of Mechanical Engineering
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Via Mersin 10, Turkey
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Email: cinar.zekimurat@gmail.com

Part 1: Participant Consent Form (PCF)

Department of Mechanical Engineering
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Via Mersin 10, Turkey
Tel: +90 392 630 1210
Fax: +90 392 365 3715
Web: https://me1.emu.edu.tr/en

Title of Study: ***Awareness and Knowledge of Industry 4.0 in Turkey***

Dear participant,

Please take a few minutes to read the following information on this research carefully before you agree to participate. If at any time you have a question regarding the study, please feel free to ask the researcher who will provide more information.

This study is being conducted by PhD Student Mr Zeki Murat Cinar under the supervision of Dr. Qasim Zeeshan and Dr Orhan Korhan. It aims to investigate the *Awareness and Knowledge of Industry 4.0 in Turkey*. The survey should take no more than 15 minutes to complete.

Of course, you are not obliged to participate in this research and are free to refuse to participate. You may also withdraw from the study at any point without giving any reason. In this case, all of your responses will be destroyed and omitted from the research. If you agree to participate in and complete the study, all responses and questionnaires will be treated confidentially. Your name and identifying information will be kept securely and separately from the rest of your questionnaire.

Data will be stored for a maximum of six years after the study. Once the data is analysed, a report of the findings may be submitted for publication.

To signify your voluntary participation, please complete the consent form below.

CONSENT FORM
Research Title: ***Awareness and Knowledge of Industry 4.0 in Turkey***
Name of Researchers: **Zeki Murat Cinar, Assoc Prof Dr. Qasim Zeeshan, Prof Dr. Orhan Korhan**
Name, Email address & Address: cinar.zekimurat@gmail.com

Please tick the boxes to confirm that you agree to each statement.

1. I confirm that I have read and understood the information sheet for this study and have had the opportunity to ask any questions. ☐

2. I understand that my participation is voluntary and that I may withdraw from the study at any time without explanation. ☐

3. I agree to take part in this study. ☐

Date Signature

Part 2: General Information

Thank you for accepting to participate in this research. This part consists of two sections as following:

Section A: OPTIONAL

By filling the information in this Section, you **agree to disclose** some of this information in the research. However, if you wish, you may fill this section as you see appropriate, and if you decide to keep this information totally **anonymous**, please proceed to **Section B**.

Name:

Email:

Your Company/Organisation Name:

Section B: MANDATORY

Kindly choose the appropriate field for each question of the following.

Type of Industry sector of your Company/Organisation:	◯ Academia & Research	◯ Aerospace, Defence & Security	◯ Agriculture	◯ Automotive	◯ Biomedical Equipment
	◯ Chemicals	◯ Computer, Electronics Equipment	◯ Construction Equipment	◯ Electrical Equipment	◯ Engineering & Construction
	◯ Energy, Oil & Gas	◯ Energy, Renewables	◯ Food & Beverages	◯ Furniture & Home Furnishing	◯ Industrial Equipment
	◯ Pharmaceuticals	◯ Rubber & Plastic Products	◯ Textile, Wearing Apparel, Garments, Leather products	◯ Transportation & logistics	◯ Wood, paper products, and printing
	◯ Other Manufacturing				
Enterprise	◯ Large (500+ employees)	◯ Medium (100 to 499 employees)	◯ Small (10 to 99 employees)	◯ Micro (less than 10 employees)	
	◯ National	◯ Multinational			
Your Job Function/ Business Area:	◯ Production/ Manufacturing	◯ Planning	◯ Research & Development	◯ Supply Chain	◯ Logistics/ Distribution
	◯ Academia	◯ Procurement/ Purchasing	◯ Marketing/ Sales	◯ Human Resource	◯ Other Please specify
Level of Management /Designation:	◯ Executive	◯ Senior Management	◯ Middle Management	◯ Junior Management	
Years of Experience:	◯ 30+ years	◯ 21-30 years	◯ 11-20 years	◯ 6-10 years	◯ 1-5 Years
Highest Educational Qualification:	◯ Doctoral Degree	◯ Master's Degree	◯ Bachelor's Degree	◯ College Degree	◯ Upper Secondary School

Part 3: Questionnaire

Section A: Level of Awareness and Knowledge.

This section is designed to assess the level of awareness of Industry 4.0 technologies. Please rate the following criteria according to your awareness level by double clicking on the appropriate check box and choosing "Checked" under default value.

	Company does not use	As of Today	In 2 years	In 5 years	Top performer
Additive Manufacturing (3D Printing)	☐	☐	☐	☐	☐
Augmented Reality	☐	☐	☐	☐	☐
Autonomous Robotics	☐	☐	☐	☐	☐
Big Data Analytics (BDA)	☐	☐	☐	☐	☐
Cloud Computing	☐	☐	☐	☐	☐
Cyber Physical Systems (CPS)	☐	☐	☐	☐	☐
Cyber Security	☐	☐	☐	☐	☐
Industrial Internet of Things (IIoT)	☐	☐	☐	☐	☐
Machine Learning	☐	☐	☐	☐	☐
Smart Sensors	☐	☐	☐	☐	☐
Real-Time Process Control Systems	☐	☐	☐	☐	☐
Wireless Communication	☐	☐	☐	☐	☐
Predictive Maintenance	☐	☐	☐	☐	☐
Vertical & Horizontal System Integration	☐	☐	☐	☐	☐
Computer Network	☐	☐	☐	☐	☐
Computer Graphics	☐	☐	☐	☐	☐
Databases	☐	☐	☐	☐	☐
Embedded Systems	☐	☐	☐	☐	☐
Computer Aided Manufacturing (CAM)	☐	☐	☐	☐	☐
Computer Aided Design (CAD)	☐	☐	☐	☐	☐
Computer Aided Engineering (CAE)	☐	☐	☐	☐	☐
Computer Aided Process Planning (CAPP)	☐	☐	☐	☐	☐
Flexible Manufacturing Systems (FMS)	☐	☐	☐	☐	☐
Numerical Control Machines (NC)	☐	☐	☐	☐	☐
Automated Material Handling Systems	☐	☐	☐	☐	☐
Environmental Control Systems	☐	☐	☐	☐	☐
Bar-coding / Automatic Identification	☐	☐	☐	☐	☐
RFID Systems	☐	☐	☐	☐	☐
Material Requirements Planning (MRP)	☐	☐	☐	☐	☐
Manufacturing Resource Planning	☐	☐	☐	☐	☐
Agile Manufacturing Systems	☐	☐	☐	☐	☐
Automated Manufacturing and Assembly	☐	☐	☐	☐	☐
Continuous material flow models	☐	☐	☐	☐	☐
Plug-in Procedure	☐	☐	☐	☐	☐
Self-Adapting Systems	☐	☐	☐	☐	☐
MES Integration	☐	☐	☐	☐	☐
Artificial Intelligence	☐	☐	☐	☐	☐
Customized Products	☐	☐	☐	☐	☐
Digital Product-Service Systems	☐	☐	☐	☐	☐
Product Lifecycle Management	☐	☐	☐	☐	☐
Digital and Connected Workstations	☐	☐	☐	☐	☐
E-Kanban	☐	☐	☐	☐	☐
End-to-end visibility	☐	☐	☐	☐	☐
Sustainable Supply Chain Design	☐	☐	☐	☐	☐
Collaboration Network Models	☐	☐	☐	☐	☐
Smart Assistance Systems	☐	☐	☐	☐	☐
Tele-Maintenance	☐	☐	☐	☐	☐
Real-Time Process Control Systems	☐	☐	☐	☐	☐
Object Self Service	☐	☐	☐	☐	☐
Servitization and Sharing Economy	☐	☐	☐	☐	☐
Intellectual Property Protection	☐	☐	☐	☐	☐
Freemium	☐	☐	☐	☐	☐
CPS Standards	☐	☐	☐	☐	☐
Automated Storage Systems	☐	☐	☐	☐	☐

Comments:

Thank you for completing Section A. Please Proceed to Section B.

Section B: Understanding the Benefits.

This section is designed to understand seen or expected benefits in your organisation from adopting industry 4.0 technologies. This information is helpful to understand the advantages of the fourth industrial revolution in different businesses. Please rate the following criteria according to your seen or expected observation.

	Very Low	Low	Moderate	High	Very High
Increased Productivity	☐	☐	☐	☐	☐
Increased Flexibility	☐	☐	☐	☐	☐
Reduced Business Costs	☐	☐	☐	☐	☐
Improved Business Turnover	☐	☐	☐	☐	☐
Enhanced Employees' Productivity	☐	☐	☐	☐	☐
Improved Product Quality	☐	☐	☐	☐	☐
Expanding Business into New Markets	☐	☐	☐	☐	☐
Developed Customers' Satisfaction	☐	☐	☐	☐	☐
Increase in Customized/Personalized Products	☐	☐	☐	☐	☐
Real-time Data Collection and Faster Decision Making	☐	☐	☐	☐	☐

If you see or expect that **all** industry 4.0 technologies **are not or will not** benefit your business on all the previous criteria, please check the next box. If you have seen or expect any benefits other than the above mentioned, please share your observations in the comments box below. ☐

Comments:

Thank you for completing Section C. Please proceed to Section G below.

Section C: Assessing the Challenges and Constraints.

This section is designed to highlight the challenges and constraints of adopting industry 4.0 technologies. The following criteria are classified into economical, technological, organisational, and human factors of concern. Please rank them according to your views in light with your current business position.

	Very Low	Low	Moderate	High	Very High
Economic Factors	☐	☐	☐	☐	☐
Unclear cost-benefit-ratio	☐	☐	☐	☐	☐
Return on Investment	☐	☐	☐	☐	☐
Insufficient Funds	☐	☐	☐	☐	☐
Other Investment Priorities	☐	☐	☐	☐	☐
Available resources for realization	☐	☐	☐	☐	☐
Technological Factors	☐	☐	☐	☐	☐
Maturity of required technologies	☐	☐	☐	☐	☐
Data Storage Capability	☐	☐	☐	☐	☐
Network Capability	☐	☐	☐	☐	☐
Data & Intelligent System Security	☐	☐	☐	☐	☐
Reliability of Technology	☐	☐	☐	☐	☐
Digital Regulations, Standards	☐	☐	☐	☐	☐
Utilization of customer data	☐	☐	☐	☐	☐
Organisational Factors	☐	☐	☐	☐	☐
Organisational Infrastructure	☐	☐	☐	☐	☐
Decentralization of processes	☐	☐	☐	☐	☐
Qualification/ Competence of workforce	☐	☐	☐	☐	☐
Awareness at Top Management Level	☐	☐	☐	☐	☐
Autonomy of employees	☐	☐	☐	☐	☐
Willingness of leaders/Commitment from Executive	☐	☐	☐	☐	☐
Openness of employees to new technology	☐	☐	☐	☐	☐
Costumer's Digital media competence	☐	☐	☐	☐	☐
Knowledge Sharing	☐	☐	☐	☐	☐
Open-innovation & cross company collaboration	☐	☐	☐	☐	☐

If you think there are other significant factors of concerns, Kindly share it in the comment box below.

Thank you very much for your time and efforts. Please answer the next part.

Section D: Standards.

Which of the following Industry 4.0 Standards you are aware?	◯ IEC 62890 - Life-cycle management	◯ IEC 61987 - Industrial-process measurement and control	◯ IEC 6130/ISO 13584 - Industrial automation systems and integration	◯ IEC 62714 - Automation Mark-up Language	◯ IEC 62264 - Enterprise-control system integration
	◯ IEC 61512 - Batch control	◯ IEC 61360 - Classification and product description	◯ IEC 62541 - Machine to machine communication	◯ IEC 61784 - Industrial communication networks	◯ IEC/TR 62794 - Reference model for the digital factory
	◯ VDMA 24582 - Condition monitoring	◯ IEC 61804 - Function blocks for process control / electronic device description language	◯ IEC 62453 - Field device tool (FDT) interface specification	◯ IEC/ISO 20140 - Energy Efficiency	◯ IEC 62443 - Network and system Security
	◯ SPARQL - RIF/SRWL - RDF(S) – OWL - W3C Semantic Web stack	◯ ISO/IEC 27000 - Information security management systems	◯ IEC 61511 - Functional safety	◯ IEC 62061 / ISO 13849 ISO 13849 - Safety of machinery	

Which of the following Industry 4.0 Standards you are using in your company?	◯ IEC 62890 - Life-cycle management	◯ IEC 61987 - Industrial-process measurement and control	◯ IEC 6130/ISO 13584 - Industrial automation systems and integration	◯ IEC 62714 - Automation Mark-up Language	◯ IEC 62264 - Enterprise-control system integration
	◯ IEC 61512 - Batch control	◯ IEC 61360 - Classification and product description	◯ IEC 62541 - Machine to machine communication	◯ IEC 61784 - Industrial communication networks	◯ IEC/TR 62794 - Reference model for the digital factory
	◯ VDMA 24582 - Condition monitoring	◯ IEC 61804 - Function blocks for process control / electronic device description language	◯ IEC 62453 - Field device tool (FDT) interface specification	◯ IEC/ISO 20140 - Energy Efficiency	◯ IEC 62443 - Network and system Security
	◯ SPARQL - RIF/SRWL - RDF(S) – OWL - W3C Semantic Web stack	◯ ISO/IEC 27000 - Information security management systems	◯ IEC 61511 - Functional safety	◯ IEC 62061 / ISO 13849 ISO 13849 - Safety of machinery	

Thank you very much for your time and efforts. Please answer the next final part.

Part 4: General Questions

This part is designed to understand your view on Industry 4.0. Kindly answer the following questions, and if you have any comments, you may leave it in the comment box below.

How do you see your business operations in the future in light with adopting industry 4.0 technologies?

Which area(s) of your business do you think/anticipate will benefit mostly from the adoption of industry 4.0 technologies (e.g. Logistics, Production, Sales, etc...)? and how would you describe the change?

What are the economical, technological and organisational challenges and constraints faced by your company/organisation in adopting industry 4.0 technologies?

Have you initiated any plans to overcome the aforementioned challenges and constraints? If yes, could you please clarify the nature of these plans?

If you have not initiated any plans, what factors are concerning your business from overcoming these challenges?

How COVID-19 has affected the adoption/transition to Industry 4.0?	
☐	Major effect. Transition is expedited
☐	Somewhat effect. Shelved
☐	Slightly effect. Transition is delayed
☐	Neither major nor minor effect. Transition going according to the plan
☐	I do not know

Comments Box:

Thank you very much for your efforts, I am very grateful for your contribution. Kindly email back the completed survey to cinar.zekimurat@gmail.com .

Appendix: Definition of Key Terms

Industry 4.0: Industry 4.0 or the fourth industrial revolution is a strategic project initiated in 2011 by the German government to create smart factories in which manufacturing technologies such as CPS, Cloud Computing and IoT are used to upgrade manufacturing systems to be able to monitor physical processes and make real-time smart decisions in collaboration with humans, machines and sensors (Lee, Bagheri and Kao, 2015).
Industrie 4.0 – The term Industrie 4.0 stands for the fourth industrial revolution, a new level of organizing and controlling the entire value chain across product lifecycles. This cycle focuses on increasingly personalized customer wishes and extends from the concept to the order, development, production, and shipping of a product to the end customer and ultimately to its recycling, including all associated services.

3D printing: A technology that produces solid objects from digital designs by building up multiple layers of plastic, resin, or other materials in a precisely determined shape (Bono, 2016).

Additive Manufacturing: is the industrial version of 3D printing. It is used to make niche items like medical implants, and to produce plastic prototypes for designers and engineers (La Monica, 2018).

Augmented Reality: A technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view. sensors (Oxford Dictionaries | English, 2018).
The real-time use of information in the form of text, graphics, audio and other virtual enhancements integrated with real-world objects. It is this "real world" element that differentiates AR from virtual reality. AR integrates and adds value to the user's interaction with the real world, versus a simulation (Gartner).

Autonomous Robots: Autonomous robots are robots that (I) can operate various tasks without the involvement of humans, (II) collect information about its nearby environment and use this information to navigate itself to reach the desired destination, (III) work for an extended period without human guidance or intervention, and (IV) move around safely in its environment while performing its assigned task without posing threat to human life, surrounding environment or itself (From et al., 2014).

Big Data: Big data refers to datasets that are too large or complex to analyze with conventional data processing procedures or methods and are subject to rapid, continuous change. Big data inverts IT priorities: Since the data is too big, the programs must now become flexible and agile. (Dumbill, 2012).

Big Data Analytics (BDA): the process of examining large data sets containing a variety of data types to uncover hidden patterns, unknown correlations, market trends, customer preferences, and other useful information (NGDATA, 2018).

Cloud: The cloud is not a single computer but a virtual "computing cloud" consisting of many interconnected computers. Users do not need to be on site to access cloud-based computers.

Cloud computing: Cloud computing refers to the provision of IT infrastructure in the form of a cloud and IT services such as data storage, data analytics, and software. This saves users the trouble of purchasing and installing costly server solutions in their own companies.
Is a general term that refers to delivering computational services through visualized and scalable resources over the internet (Zhong et al., 2017).

Cyber-physical systems: CPS link the physical and virtual worlds by communicating through a data infrastructure, the Internet of Things. They are the framework that make it possible to generate a virtual model of real production, analyse all the datastreams that arise from sensors and other IT systems, and map their interrelationships.
CPS is a mechanism through which physical objects and software are closely intertwined, enabling different components to interact with each other in a myriad of ways to exchange information (Zhong et al., 2017).

Cybersecurity: is the body of technologies, processes and practices designed to protect networks, computers, programs and data from attack, damage or unauthorized access (Techtarget.com, 2018).

Data analytics: Data analytics describes the process of analyzing a company's big data and finding useful interrelationships that support the company's activities. Given the enormous volumes of data in businesses today, data can only yield an added value if it can be placed in context and consolidated under larger categories.

Data-driven services: Data-driven services as defined here include telemaintenance; optimized resource consumption of machinery; availability, performance, and quality enhancements through optimized parameter settings; etc. The objective of datadriven services is to align future business models and enhance the benefit to the customer. The after-sales and services business will be based more and more on the evaluation and analysis of collected data and rely on enterprise-wide integration. The physical products themselves must be equipped with physical IT so they can send, receive, or process the information needed for the operational processes. This means they have a physical and digital component, which in turn are the basis for digitized services in the usage phase of the products.

Digital modelling: A digital model is composed of product-related data supplemented by transaction data, geopositioning data, and other data.

ERP systems: ERP systems offer integrated software solutions for administering, planning, and controlling a company's value-adding processes, thereby providing the foundation for information processing in the company. Today's ERP systems focus on extending functionalities by integrating various functionally specialized systems through advanced planning and scheduling (APS).

Horizontal integration: Horizontal integration in production and automation technology describes the consolidation of various IT systems into an end-to-end solution. It involves the various process steps of production and corporate planning between which material, energy, and information flows. Horizontal integration takes place both within a company and across various companies. The smart factory constantly adapts to new circumstances (such as the order volume or availability of materials) and automatically optimizes its production processes. It does this through integration with suppliers and customers in the value chain.
Industrial Internet of Things (IoT): refers to an information network of physical objects such as electronic sensors, machines, vehicles, buildings and other objects that allows the connection and interaction between these objects to exchange and collect data (Xia et al., 2012).

Information and communications technology (ICT): Information and communications technology refers to all technical devices and systems that can digitize, process, store, and transmit information of any kind.

M2M – Machine-to-machine communications: M2M stands for the automated exchange of information among technical systems or between systems and a central unit. Typical applications include remote monitoring and control. M2M links information and communications technology and forms the Internet of Things.

MES: A manufacturing execution system (MES) constitutes the process-oriented operating level of a multilayer production management system. It is directly linked to the process automation systems. MES, in contrast to ERP systems, features integrated APS logic, which allows more precise and detailed fine-tuning and control as well as better real-time capability.

Predictive maintenance: Predictive maintenance systems are designed to detect machine errors such as interruptions or outages before they happen. The aim is to prevents errors through maintenance and proactive repairs.

Rapid prototyping: A group of techniques used to quickly create a model of a physical part or assembly using three-dimensional computer aided design data. Construction of the part or assembly is usually done using 3D printing or "additive layer manufacturing" technology

RFID: Refers to an automated data collection technology that uses radio frequency waves to transfer data between a reader and a tag to identify, track and locate the tagged item (Gartner). Radio frequency identification can be used for monitoring, quality control, automatic adaptation of the production process, and to identify and share information on an item itself and its environment.

SCM system: Supply chain management systems create cross-enterprise transparency relating to needs, capacities, and inventory along the value chain to support individual companies in their decision-making processes or operational workflows in real time.

Smart factory: Smart factory refers to an intelligent, interconnected factory. Successful implementation of Industrie 4.0 enables distributed, highly automated production. Unlike in traditional production, smart workpieces will control and monitor the production process and, in the final expansion phase, guide themselves autonomously through production. This happens in the environment of the smart factory. The smart factory is a production environment in which the production systems and logistics systems largely organize themselves without human intervention. The smart factory relies on cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things. Industrie 4.0 also involves digital modeling through the smart gathering, storage, and processing of data. In this way, the smart factory concept ensures that information is delivered and resources are used more efficiently. This requires the real-time, cross-enterprise collaboration between production systems, information systems, and people. These integrated systems produce huge amounts of data that are processed, analyzed, and integrated into decision-making models.

Smart operations: Smart operations refer to the horizontal and vertical integration of the company, which enables flexible production planning and control. One hallmark of Industrie 4.0 is the enterprise-wide and cross-enterprise integration of the physical and virtual worlds. The advent of digitization and the plethora of data it has brought to production and logistics have made it possible to introduce what are in some cases entirely new forms and approaches to production planning systems (PPS) and supply chain management (SCM). The technical requirements in production and production planning necessary to realize the self-controlling workpiece are known as smart operations.

Smart products: Smart products are physical objects equipped with ICT so they are uniquely identifiable and can interact with their environment.
They use sensor technology to record their environment and their own status and offer various add-on functionalities in operation. Smart products have information about their own production process and can gather and transmit data during the manufacturing and usage phase. This makes it possible to obtain a digital model of the smart factory and offer data-driven services to customers during the usage phase.
Smart products are a vital component of a unified "smart factory" concept facilitating automated, flexible, efficient production. Physical products are equipped with ICT components (sensors, RFID, communications interface, etc.) to collect data on their environment and their own status. Only when products gather data, know their way through production, and communicate with the higher-level systems can production processes be improved and guided autonomously and in real time. It also becomes possible to monitor and optimize the status of the individual products. This has potential applications beyond production alone. Using smart products during the usage phase makes new services possible in the first place – through communications between customers and manufacturers, for example.

Smart services: Smart services are packages of products and services individually configured over the Internet (acatech, 2014). The services include predictive remote services and new business models such as the trade in production capacities and production data.

Telemaintenance: Telemaintenance refers to computer-controlled remote maintenance of machinery and machine parameters.

Vertical integration: Vertical integration in production and automation technology refers to the integration of various IT systems and various hierarchical levels of production and corporate planning into a single end-to-end solution. Examples of such hierarchical levels include the actor and sensor level, the control level, or the production control level. People, machinery, and resources are digitally modeled in the smart factory, communicating with one another through cyber-physical systems (CPS).

Vertical & Horizontal System Integration: Integrating manufacturing systems vertically and horizontally across the value chain achieving end-to-end digital engineering.

Virtual reality: Provides a computer-generated 3D environment that surrounds a user and responds to that individual's actions in a natural way, usually through immersive head-mounted displays and head tracking (Gartner).

Appendix E: Bibliography

Zeki Murat ÇINAR received a B.S. in Mechatronics Engineering and M.S. in Mechanical Engineering from Eastern Mediterranean University (EMU), North Cyprus, Turkey in 2015 and 2017 respectively. Currently, he is a doctoral research associate at the Department of Mechanical Engineering, Eastern Mediterranean University. He is also working as a Process Development Engineer at BORGWARNER. His research interests include smart manufacturing systems, optimization, machine learning, and industry 4.0 technologies.

List of Publications:

1. Cinar, Z.; Asmael, M.; Zeeshan, Q. Developments in Plasma Arc Cutting (PAC) of Steel Alloys: A Review. Jurnal Kejuruteraan 2018, 30, 7-16.
2. Cinar, Z.M.; Nuhu, A.A.; Zeeshan, Q.; Korhan, O. Digital Twins for Industry 4.0: A Review. In Calisir F., Korhan O. (eds) Industrial Engineering in the Digital Disruption Era. GJCIE 2019., Lecture Notes in Management and Industrial Engineering. Springer, Cham.: 2020; https://doi.org/10.1007/978-3-030-42416-9_18 pp. 193-203.
3. Cinar, Z.M.; Zeeshan, Q.; Solyali, D.; Korhan, O. Simulation of Factory 4.0: A Review. In Calisir F., Korhan O. (eds) Industrial Engineering in the Digital Disruption Era. GJCIE 2019, Lecture Notes in Management and Industrial Engineering. Springer, Cham.: 2020; https://doi.org/10.1007/978-3-030-42416-9_19 pp. 204-216.
4. Fallaha, M.; Cinar, Z.M.; Korhan, O.; Zeeshan, Q. Operator 4.0 and Cognitive Ergonomics. In Calisir F., Korhan O. (eds) Industrial Engineering in the Digital

Disruption Era. GJCIE 2019, Lecture Notes in Management and Industrial Engineering. Springer, Cham.: 2020; https://doi.org/10.1007/978-3-030-42416-9_20 pp. 217-228.

5. Cinar, Z.M.; Zeeshan, Q.; Korhan, O. Recent Developments of Automated Storage & Retrieval System (AS/RS). In Calisir F. (eds) Industrial Engineering in the Digital Disruption Era. GJCIE 2020, Lecture Notes in Management and Industrial Engineering. Springer, Cham.: 2021.
6. Çınar, Z.M.; Abdussalam Nuhu, A.; Zeeshan, Q.; Korhan, O.; Asmael, M.; Safaei, B. Machine learning in predictive maintenance towards sustainable smart manufacturing in industry 4.0. Sustainability 2020, 12, 8211.
7. Cinar, Z.; Asmael, M.; Zeeshan, Q.; Safaei, B. Effect of Springback on A6061 Sheet Metal Bending: A Review. Jurnal Kejuruteraan 2021, 33, 13-26.

Appendix F: Ethical Approval Form

Doğu Akdeniz Üniversitesi
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Eastern Mediterranean University
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Etik Kurulu / *Ethics Committee*

Reference No: ETK00-2020-0220 11.11.2020

Subject: Your application for ethical approval.

Re: Zeki Murat Çınar (17600016)
Faculty of Engineering

EMU's Scientific Research and Publication Ethics Board (BAYEK) has approved the decision of the Ethics Board of Engineering (date: 30.10.2020, issue: 2020/4) granting Zeki Murat Çınar from the Faculty of Engineering to pursue with his PhD thesis work titled **"A Framework for Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises (A Case Study of Turkey)"** supervised by Assoc. Prof. Dr. Orhan Korhan and Assoc. Prof. Dr. Qasim Zeeshan.

Prof. Dr. Yücel Vural
Chair, Board of Scientific Research and Publication Ethics - EMU

YV/ns.

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