ASSESSING THE READINESS OF MANUFACTURING FIRMS FOR THE ADOPTION OF INDUSTRY 4.0 IN PAKISTAN: DRIVERS AND BARRIERS

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MS L&SCM 2K19

A thesis submitted to NUST Business School for the partial fulfillment of the degree of Master of Science in Logistics and Supply Chain Management.

2023

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DECLARATION

I hereby state that no portion of the work referred to in this dissertation has been submitted in support of an application for another degree or qualification of this or any other University or other institute of learning.

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ACKNOWLEDGEMENT

All Praise and glory to Allah Almighty the Gracious the Merciful, Who bestowed on me His blessings and strong will to complete this project.

First and foremost, I would like to thank my esteemed supervisor Dr. Mujtaba Hassan Agha for his invaluable supervision, continuous support, and patience during my MS research thesis. Without his support and guidance, this would have not been possible. I would like to express my gratitude to GEC members Dr. Faran Ahmed and Dr. Waqas Ahmed for their support, guidance, and insightful comments which led to the completion of this thesis. I would like to extend my gratitude to Dr. Muhammad Moazzam for his guidance and motivation.

Immense gratitude for my beloved mother, who is the guiding light of my life and a constant source of motivation to pursue my goals. My appreciation also goes out to my family and friends for their encouragement and support throughout my studies.

Nadia Perveen

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List of Acronyms

No.	Phrase	Abbreviation
1	Supply Chain	SC
2	Cyber-Physical System	CPS
3	Internet of Things	IoT
4	Artificial Intelligence	AI
5	Industrial Internet of Things	IIoT
6	United State of America	USA
7	Analytical Hierarchical Process	AHP
8	Technological Organizational Environment	TOE
9	Enterprise Resource Planning	ERP
10	Global Positioning System	GPS
11	Government	Govt
12	Small Medium Enterprises	SMEs
13	Information Technology	IT

ABSTRACT

Industry 4.0 is an umbrella term that entails many advanced technologies, procedures, and systems to make business processes more efficient, flexible, autonomous, and dynamic. An exponential growth in advanced technologies indicates that many economies are undergoing a steady digital transformation. Industry 4.0 will impact every manufacturing, supply chain management and logistic sector domain. It has become one of the key strategic management objectives in recent years. To enhance business competitiveness in the future, firms need to make strategic and long-term investments in advanced technologies. The first step towards Industry 4.0 implementation is to know the firm's current status, i.e., how much a firm is prepared to invest in adopting new technologies. This thesis is divided into two studies. The first study aims to assess the readiness of manufacturing firms for the adoption of Industry 4.0 in Pakistan.

The second study aims to identify and evaluate to prioritize/rank Industry 4.0 adoption drivers and barriers by using Analytical Hierarchy Process (AHP) technique. Industry 4.0 implementation has several benefits and drivers (e.g., cost reduction, customer requirement, increased innovation, improved sustainability, increased productivity & efficiency etc.) that motivate firms to adopt it. On the other hand, some Industry 4.0 implementation barriers (organizational, financial, technological, lack of Govt support, lack of clarity regarding economic benefits, and security risk etc.) hinder its adoption. Identifying and evaluating drivers and barriers is important to make effective decisions.

The first study's findings show that Pakistani manufacturing firms are not ready to adopt Industry 4.0. The second study's findings indicate that financial incentives, customer requirements, and increased productivity and efficiency are the important driving factors that encourage Industry 4.0 adoption. While organizational, financial, and lack of government support are the most critical barriers impeding Industry 4.0 adoption in Pakistan.

Keywords: Industry 4.0, the readiness of Industry 4.0, manufacturing firms, Industry 4.0 drivers, Industry 4.0 barriers, Analytical Hierarchy Process (AHP)

CHAPTER 1

INTRODUCTION

1.1. Background

The term “Industry 4.0” is used for the fourth industrial revolution (Vaidya, Ambad, & Bhosle, 2018). The first industrial revolution began in 1760 with the invention of the steam engine, which triggered the transition from handicrafts and agrarian economies to industrial development and machine production (Atik & Ünlü, 2019). Railways were the primary means of transportation, and coal was the main energy source at that time. The textile and steel sectors dominated in terms of output value, employment, and capital investment (Hofmann & Rüsch, 2017). In 1900, the second industrial revolution was initiated with the development of the internal combustion engine and electricity, which led to rapid industrialization and mass production. Mass production refers to manufacturing high volumes of products (large quantities of standardized products) at low cost by using assembly lines and machines (Yin, Stecke, & Li, 2018). Mass production was facilitated by electricity and oil (Arden et al., 2021; L. D. Xu, Xu, & Li, 2018).

The third industrial revolution, initiated in 1960, led to an information society using electronics, information & communication technologies, and computers to automate production (X. Xu, Lu, Vogel-Heuser, & Wang, 2021). The main focus of the third industrial revolution was mass customization (Tien, 2020). The present era is the fourth industrial revolution, which is building on the third revolution and is characterized by the convergence of advanced technologies and cyber-physical systems (M. Xu, David, & Kim, 2018). The development of Internet of Things (IoT), Artificial Intelligence (AI), mobile technologies, and other advanced technologies facilitates real-time decision-making and advancing mass customization into real-time customization (Tien, 2020).

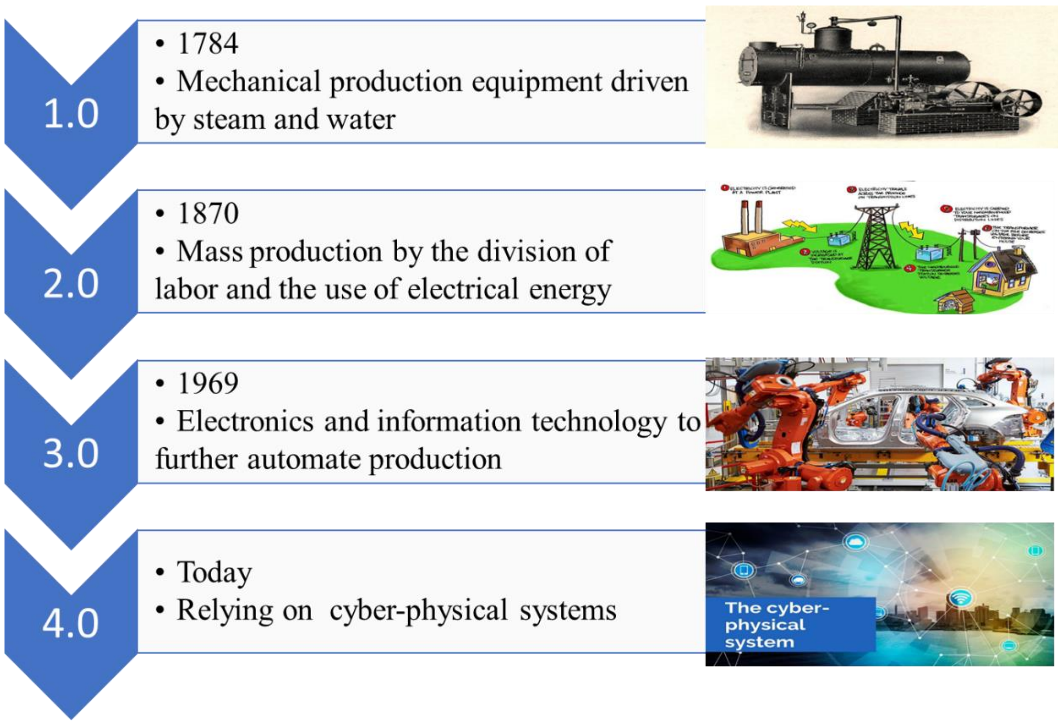

Figure 1: Main Characteristics of industrial revolutions (L. D. Xu et al., 2018).

Table 1: The four stages of the industrial revolution (Karimulla, 2020; Ślusarczyk, 2018)

Period	Resources of energy	Main technical achievement	Main developed industries	Ways of transportation
1.0:1760-1900	Coal	Steam engine	Textile, auto, steel, machine building	Train
2.0: 1900-1960	Oil & Electricity	Internal combustion engine	Auto, chemistry	Car, Plane
3.0: 1960-2000	Natural gas & Nuclear energy	Computers, robots	IT, Electronics	Car, Planes, fast trains
4.0:2000-Present	Green energies	IoT, CPS, 3D printer, genetic engineering, etc.	High technology industries	Ultra-fast trains and Electric car

Today's transformations herald the arrival of a distinct industrial revolution rather than merely a continuation of the third one due to three reasons i.e., scope, velocity, and system impact. The first reason is its broad scope; the fourth industrial revolution is disrupting virtually every industry domain in every country. The second reason is velocity, the fourth revolution is based on the third industrial revolution, which was characterized by the rapid advancement of electronics, information technology (IT), and digitalization. But fourth revolution is developing exponentially rather than linearly compared to prior ones (Setyaningsih, Kelle, & Maretan, 2020). The third reason is system impact, the magnitude and complexity of these shifts indicate a complete systemic transformation in terms of management, production, and governance (M. Xu et al., 2018).

Industry 4.0 is a broad term that refers to various technologies, procedures, and systems intended to improve production processes' accuracy, adaptability, autonomy, and responsiveness (Hofmann & Rüsch, 2017). Industry 4.0 is beyond automation (Karimulla, 2020). Being a company 4.0 entails increasing one's degree of knowledge & expertise, vigorously applying advanced technologies, and focusing on the processes by which a company's supply chain (SC) and its human, physical, and information resources are more tightly integrated and collaborated to generate additional value in the company (Tortora, Maria, Iannone, & Pianese, 2021).

An exponential growth in advanced technologies indicates that many economies are undergoing a steady digital revolution (Karimulla, Gupta, Mashinini, Nkosi, & Anghel, 2020). Industry 4.0 development significantly impacts the manufacturing sector. Industries in developed countries like North America and Europe are building their production processes using cyber-physical systems (CPS) (Sriram & Vinodh, 2020). These systems use technology built on the integration of production-based sensors, machine learning, wireless systems, and wireless control systems, creating a platform for new production systems that integrate physical and computer abilities. The CPS is equipped with the sensor technologies to receive physical data and convert it into digital signals. By exchanging this information and gaining access to the data that links it to digital networks, they can create an “Internet of Things” (IoT) (Bravi & Murmura, 2021).

The cutting-edge technologies of Industry 4.0 will affect every single domain of manufacturing, supply chain management, and logistics. Therefore, every industry’s future will depend upon technology and innovation. Since the fourth industrial revolution, every sector has undergone a swift transformation (Culot et al., 2020).

Countries undergoing a global digital transition are more likely to be market competitors (Karimulla, 2020). The Industry 4.0 initiative by the German government has inspired many other countries to introduce similar plans to stay competitive in the market (Rajnai & Kocsis, 2018). Amongst these countries, the United States of America (USA) has made the most investment towards Industry 4.0 adoption, or smart manufacturing as it is more commonly known in the USA (Bauer et al., 2016). The USA, Germany, and Japan are regarded as leaders in innovation and technology. These countries are renowned for their technological advancements and ongoing scientific research (Bakhtari, Waris, Sanin, & Szczerbicki, 2021).

In all industries and business environments, changes are occurring rapidly. Dynamic demand patterns, cost pressures, intense competition, and short-term market demands characterize today's marketplace. In the current dynamic environment, it has become critical to ensure the competitiveness of manufacturing firms (Sriram & Vinodh, 2020). According to Pacchini et al. (2019), enterprises must be prepared for the new competitive challenge in the current business environment. Industry 4.0 provides a platform that combines various advanced technologies to overcome these challenges (Vrchota & Pech, 2019). Industry 4.0 advanced technologies have the full potential to automate and integrate different business processes, people and machines, decentralized workflows, and digitalized production systems, which bring many benefits to organizations (Culot et al., 2020). Implementing Industry 4.0 advanced technologies brings several economic, social, and environmental benefits.

Industry 4.0 has become one of the key strategic management objectives in recent years. The employment of advanced technologies makes strategic and long-term investments more necessary to improve the competitiveness of businesses in the future (Bravi & Murmura, 2021). Many manufacturing firms have already started implementing advanced technologies and smart procedures. Some of the companies mention their practical experience with these technologies. They utilize advanced technologies, at least partially. In addition to efficiency and productivity improvements, Industry 4.0 demonstrates a shift in emphasis from mass production to mass customization, focusing on customers' customized requirements and preferences (Bauer et al., 2016). Moreover, Industry 4.0 components are giving rise to innovative and disruptive business models (Stock & Seliger, 2016).

The management of many enterprises considers their future strategies and steps to stay competitive in such a dynamic environment. The Industry 4.0 current challenges force managers to assess their readiness to adopt such changes. Managers often wonder how things are going, what situation is in their companies, and in which technologies they should invest. The first step for effective implementation of Industry 4.0 is to know the current status of preparation of the firms to plan, make effective strategies, allocate resources efficiently, etc. The first study assessed the readiness of manufacturing firms to adopt Industry 4.0 in Pakistan. Manufacturing industries are becoming more interested in implementing Industry 4.0 because of their eagerness to become competitive in today's dynamic markets and due to other Industry 4.0 drivers e.g., cost reduction, customer requirement, increased innovation, improved sustainability, and increased productivity & efficiency (Bakhtari et al., 2021; Waris, Sanin, & Szczerbicki, 2018). Besides knowing Industry 4.0 drivers, it is important to identify the Industry 4.0 implementation barriers (e.g., organizational, financial, technological, lack of Govt support, lack of clarity regarding economic benefits, and security risk, etc.) that firms may face while implementing Industry 4.0 and determine which one will affect more. Only then can strategic actions be taken to manage these obstacles (Bakhtari et al., 2021).

Industry 4.0 is characterized by six design principles; modularity, decentralization, interoperability, virtualization, real-time capabilities, and service orientation (Hermann, Pentek, & Otto, 2016; Koh, Orzes, & Jia, 2019). Industry 4.0 enabling technologies include CPS, Cloud Computing (Pacchini, Lucato, Facchini, & Mummolo), IoT, Artificial Intelligence (AI), Machine Learning, Block Chain technology, Advanced Robotics, Cybersecurity systems, Simulation & Modeling, Visualization Technologies, Big Data Analysis, 3D Printing, Digital Twin, New Materials, 5G, etc. (Culot, Nassimbeni, Orzes, & Sartor, 2020; Guo, Li, Zhong, & Huang, 2020; Zheng, Ardolino, Bacchetti, & Perona, 2021). The literature review section discusses the Industry 4.0 design principles and enabling technologies.

1.2. Problem Statement

The Industry 4.0 adoption promises many benefits for firms, but its implementation has many challenges. The manufacturing industries are under pressure to enhance their productivity and responsiveness due to demanding customers, the need for constant innovation, and dynamic market conditions (Hofmann & Rüsch, 2017). Although businesses strive hard to adopt Industry 4.0 technologies successfully, but the transformation is complex. According to McKinsey's Global Expert Survey, only four out of ten Industry 4.0 technologies implementations have made good progress, and the average also differs significantly across nations (Bauer et al., 2016; Raj, Dwivedi, Sharma, de Sousa Jabbour, & Rajak, 2020). So, the failure rate for Industry 4.0 adoption is very high, which is a serious concern for businesses who want to adopt it.

Going digital is a process that involves numerous steps to incorporate technological and organizational changes. The first step is to prepare for Industry 4.0 implementation. The three major steps/stages of adopting Industry 4.0 are shown below.

Figure 2: Different stages of Industry 4.0 Implementation.

The one critical reason for Industry 4.0 adoption failure is the lack of knowledge and lack of readiness of firms to adopt it. Most firms ignore the first step, readiness, which is the prerequisite for adopting Industry 4.0. To be prepared to adopt Industry 4.0, the management must clearly understand the current situation and a strategic plan outlining what should be accomplished before the company's digital transformation can begin (Rajnai & Kocsis, 2018).

Industrial managers must employ disruptive technologies and integrate the most recent developments to increase productivity and efficiency if they want to stay competitive in the market and avoid extinction. Knowing about the Industry 4.0 drivers is important to motivate firms to invest and focus on important drivers. However, industrial managers may encounter some barriers which impede progress as they implement advancement for Industry 4.0 adoption into practice; so along with assessing the readiness, management must also identify and evaluate drivers and barriers to devise strategies for successful adoption (Bakhtari et al., 2021).

Hence, this raises questions:

How ready or prepared is the manufacturing sector in Pakistan to adopt Industry 4.0? What are the key drivers and barriers to adopting Industry 4.0 for the manufacturing sector of Pakistan? Furthermore, which drivers and barriers are more critical for manufacturing firms in Pakistan context?

1.3. Research Aim

This research includes two subsequent studies. The first study aims to assess the readiness of manufacturing firms for Industry 4.0 adoption in Pakistan. For this reason, researcher have analyzed some previous Industry 4.0 Readiness Assessment Models, compared their dimensions and sub-dimensions, and created a comprehensive framework to assess Industry 4.0 readiness. Considering the national and regional context, researcher designed a questionnaire for the survey and carried out different data collection campaigns to evaluate Industry 4.0 readiness.

The second study aims to identify, evaluate, and rank the critical Industry 4.0 adoption drivers and barriers for manufacturing firms in Pakistan. For this purpose, researchers interviewed industry experts for their expert opinion to evaluate and rank Industry 4.0 drivers and barriers by using the Analytical Hierarchy Process (AHP) technique.

1.4. Research Objectives

The objects of the study are given below:

i. To assess the readiness of the manufacturing sector for Industry 4.0 adoption in Pakistan.

ii. Identify key Industry 4.0 adoption drivers and barriers for manufacturing firms in Pakistan.
iii. To evaluate and rank key drivers and barriers for adoption of Industry 4.0 in context of manufacturing sector of Pakistan.

1.5. Research Question

Below are the research questions raised:

Q.No.1: How much of the manufacturing sector of Pakistan is ready to adopt Industry 4.0?

Q.No.2: What are the key Industry 4.0 adoption drivers and barriers for the manufacturing firms of developing economies?

Q.No.3: Which Industry 4.0 adoption drivers and barriers are more critical?

1.6. Justification

The scientific literature has worked on the theoretical and conceptual framework of Industry 4.0, identified Industry 4.0 adoption drivers and barriers for developed countries, developed numerous models and techniques to carry out assessments of the level of digital maturity, and created roadmaps to assist businesses in implementing or realizing a digital transformation. However, the connection between theory and practice is still limited as conceptual models and frameworks are not validated in real-world applications. However, there is lack of thorough research on the analysis of actual manufacturing setting and what developments and implementations are being carried in the business world (Karimulla, 2020; Tortora et al., 2021).

The very first step to support an organizations' digital transformation is to assess one's digital readiness, analyze their capabilities and make strategies to incorporate improvements (Machado et al., 2019). One Industry 4.0 assessment model is not applicable to all organizations, and digitization exhibits characteristics similar to the artisan mentality (Bravi & Murmura, 2021). Several researchers agree that there is limited literature on the specific topic and a lack of practical studies on Industry 4.0 readiness in manufacturing sector. For this study, this scant evidence serves as research motivation for this study. Phuyal, Bista, and Bista (2020) indicated that future studies should focus on the manufacturing sector for implementing advanced technologies to improve productivity and performance. Wang, Shou, Wang, Shou, Wang, Dai, and Wang (2019) find that small and medium enterprises are prone to adopting smart manufacturing. In the fourth industrial revolution, companies must assess their Industry 4.0 readiness for effective decision making to maintain or improve competitiveness to survive and succeed (Rajnai & Kocsis, 2018; Soomro, Hizam-Hanafiah, Abdullah, Ali, & Jusoh, 2021).

Culot et al. (2020) believe that as long as Industry 4.0 is still under development, there are great prospects for future study. Since the scientific community is experiencing an "announced" revolution, there is an opportunity to play an active part in giving crucial information and assisting with translating this vision into reality. The development of advanced technologies and evaluation of their effects in various industrial settings have received significant attention in scientific literature up to this point. However, few studies provide practical analysis about how manufacturing organizations deal with the digital transition, particularly for manufacturing sectors.

Among the long list of advantages, Industry 4.0 have full potential to redesign manufacturing firms' business models, increase productivity, enhance quality, and improve working conditions. However, high cost, lack of awareness, changes to legacy systems, and energy have been identified as challenges for adopting Industry 4.0. Given these potential advantages, it has drawn much attention from scholars and practitioners (Bai, Dallasega, Orzes, & Sarkis, 2020).

The shift will inevitably present challenges that are far more deeply ingrained in the realities of small businesses. Manufacturing firms' evolutionary trajectories may be slowed down by factors like a shortage of funds, expensive labor, a lethargic bureaucracy, structural issues, and a limited spread of technologies. The primary challenge facing these businesses is leveraging technology to improve organizational efficiency. The concept of Industry 4.0 is not well understood and its advanced technologies implementation in manufacturing sector. Moreover, they cannot assess their operations for technological and digital gaps and lack knowledge of integrating cutting-edge technology into their production process to execute the Industry 4.0 paradigm (Tortora et al., 2021). According to some researchers, the practitioners' perceptions and opinions may differ significantly across countries.

1.7. Scope and Significance of the study

This study will be equally useful and provide implications for policymakers, practitioners, and researchers. It will help to understand Industry 4.0 initiatives in depth and help professionals who are considering adopting Industry 4.0 make informed decisions. Hence, it will help practitioners and consultants in decision-making, planning, allocating the firm's resources, and formulating effective strategies to overcome potential challenges for successfully implementing these initiatives.

It can guide the government and policymakers in devising effective regulations, policies, and programs to promote such initiatives. It will outline new research opportunities for academic researchers that could be addressed in future studies.

CHAPTER 2

LITERATURE REVIEW

This chapter discus the concept of Industry 4.0, its design principles, enabling technologies, Industry 4.0 readiness, readiness assessment models along with the Industry 4.0 adoption drivers and barriers from the existing literature.

2.1 Theoretical Background

The study draws on the theoretical basis of the Technological, Organizational and Environmental (TOE) framework to explain the adoption of Industry 4.0 technologies. TOE framework, was first introduced by ‘Louis G. Tornatzky and Mitchell Fleischer’ in 1990 (Queiroz, Pereira, Telles, & Machado, 2019). This theoretical framework explain implementation of innovation at the organizational level that describes environmental, organizational, and technological settings influencing the implementation of Industry 4.0 technological breakthroughs (Lorenz, Benninghaus, Friedli, & Netland, 2020). The TOE framework is one of the most extensively utilized theoretical foundations to explain information and digital technologies (IDTs) adoption, for instance, diffusion and implementation of cloud computing, big data analytics, and industrial robots based on artificial intelligence (AI) (Bai et al., 2020).

The technological determinants of the TOE framework have context in terms of technological innovations applicable to a business as well as market-available technology (Forcina & Falcone, 2021). The *technological determinants of Industry 4.0 adoption* comprise of Industry 4.0 technologies available in the market that can be acquired and employed are classified under the *Technological* dimension of TOE. The *organizational determinants of Industry 4.0 adoption* are related to the organization’s context. The organizational dimension refers to the intra-organizational and resource-based aspect of the organization including the characteristics of human resources, organization structure, culture and communication etc. (Bigliardi, Bottani, & Casella, 2020). The environmental dimension refers to external factors that may influence the firm’s adoption of technology. The *environmental determinants of Industry 4.0 adoption* includes an organization/firm’s external stakeholders, industry structure, competitors, Govt etc. (Lorenz et al., 2020).

2.2. Industry 4.0

In 2011, a working group of the Ministry of Education and Research, Germany, first used the term "Industry 4.0” at a fair in Hanover, Germany. This term was later adopted by the German government in 2013 for the strategic initiative that they took to revolutionize their manufacturing sector (Roblek, Meško, & Krapež, 2016; L. D. Xu et al., 2018). Industry 4.0 is a revolutionary concept which states that all manufacturing firms should be personalized through the integration of production processes as well as cutting-edge technologies and procedures (Da Silva, Kovaleski, Pagani, Silva, & Corsi, 2020). The terms "Industry 4.0" and "fourth industrial revolution" are often used interchangeably (Bai et al., 2020). The fourth industrial revolution is referred to by several names or acronyms in literature, including "Industry 4.0," "Smart Factory," "Smart Manufacturing," "Industrial Internet," "Internet of Everything," "Intelligent Manufacturing," and "Digital Transformation," etc., but "Industry 4.0" is a commonly and extensively used term and has become de facto for the new phenomenon (Culot et al., 2020).

From last few years, practitioners, researchers, and policymakers have become ever more interested in this emerging field (Chauhan & Singh, 2019). The current research publications reveal a significant gap in the phenomenon’s conception. There is no clear-cut or agreed-upon definition of "Industry 4.0." The dearth of a generally agreed knowledge of Industry 4.0 has created ambiguity, which is the main hindrance to the theoretical foundations of academic research (Hermann et al., 2016). Even though there is no much consensus on what defines Industry 4.0, at a minimum, Industry 4.0 is "cyber-physical systems' integration into manufacturing and logistics, their connectivity through the Internet of Things (IoT), and services for the ramifications of value generation and business models for work organization and downstream services" (Rymarczyk, 2020).

S. Kumar, Suhaib, and Asjad (2020) defined it as, "Industry 4.0 is a common term that is used for highly sophisticated and automated manufacturing systems, business processes, and services in which devices are self-aware, can communicate with one another and with humans, and could be remotely accessed and could take immediate corrective decisions and actions based on the situation using artificial intelligence, previous experience, and cloud and network-based data." The Industry 4.0 foundations are based on people, machines, and logistics, which are connected together to share information, process data, and make effective decisions. In doing so, smart technologies, such as smart equipment and smart factories, are used to accomplish cost- and time-effective production targets (Karimulla, 2020). Industry 4.0's common defining elements include key enabling technologies, other enablers, and distinctive characteristics. Advanced technologies, real-time availability of data, cyber-physical systems (CPSs), the ability to identify an optimum process at any given time by using information, and the integration of processes, machines, systems, and people into the value chain all contribute to the technological foundation of Industry 4.0. But it's crucial to match technological advancement with reality (Tortora et al., 2021).

The following section discusses the theoretical background behind the main enabling technologies of Industry 4.0 that are essential to creating future smart factories built on Industry 4.0.

2.2.1. Enabling Technologies

In recent years, many Industry 4.0 enabling technologies have emerged. Since this field of study is relatively new, there are a variety of opinions on what constitutes "Industry 4.0." Some common emerging Industry 4.0 technologies comprise cyber-physical systems; big data (BD); Internet of Things (IoT); cloud computing; cybersecurity systems; blockchain technology, simulation & modeling, visualization technologies, artificial intelligence, machine learning, advanced robotics, 3D printing, new materials, digital twin, 5G, etc. (Bravi & Murmura, 2021; Bull, 2021; Culot et al., 2020; Koh et al., 2019; Lorenz et al., 2020; Queiroz et al., 2019). However, there is no agreed-upon list of Industry 4.0 technologies in the literature: lack of shared understanding among scholars. There are also some discrepancies that exist within various literature fields (Zheng et al., 2021). The notion behind an Industry 4.0 supply chain is basically the amalgam of these emerging technologies working autonomously along a networked supply chain to increase productivity and solve complex challenges in real-time by using AI, BD analytics, and heterogeneously connected sensors and devices (Bull, 2021).

Cyber-Physical Systems (CPS)

These are the automated systems that allow the integration of computing and communication infrastructure with the operations of physical reality (Bigliardi et al., 2020). At a minimum, the use of CPSs is a requisite for entry into Industry 4.0. CPSs are complex in design, interconnected with actuators and sensors, data stores, software, and a variety of heterogeneous devices scattered all over a supply chain to enable autonomous, real-time adjustments and optimize production value. This complex technology is still in development; however, it promises to provide the manufacturing firms that can afford it with increased productivity, flexibility, and a competitive edge in a fast-evolving global market (Rymarczyk, 2020).

Artificial Intelligence

Artificial intelligence being a sub-field of computer science involves the development of intelligent machines, functioning and responding a way similar to humans (Forcina & Falcone, 2021). Artificial intelligence, often known as machine intelligence, refers to a device's capacity to understand its surroundings and act on its own to increase its chances of success. Complex algorithms of artificial intelligence can not only learn and analyze various pieces of data and information but are also able to recognize texts, pictures, speech, and people. Texts can be translated, decision-making skills can be learned, technical production issues can be tracked, reported, and resolved, bank customers' creditworthiness can be determined, marketing strategies can be planned, songs can be written, and so on. Artificial intelligence can be used in the supply chain and value generation phases, completely changing the business paradigm (Guo et al., 2020).

Machine learning refers to a set of computer techniques that involves the extraction of valuable knowledge and makes suitable decisions from the bulk quantities of both structured and unstructured data. This big data can be accessed at any point from a firm or business (Bigliardi et al., 2020).

Advanced Robots

In production, robots are employed to mimic human actions. Cyber-physical machines known as “advanced robots” can function partially or entirely independently using computer algorithms. They mix physical components and artificial intelligence (Frank, Dalenogare, & Ayala, 2019). The upgraded communication network provide expanded capabilities that have made possible for the advance robots to learn various tasks without any formal programming being done as well as communicate with human operators autonomously and other autonomous devices (Vaidya et al., 2018).

A smart factory can use robots in a variety of ways. They apply to almost every aspect of human activity and, most importantly, will form the cornerstone of an intelligent factory's operation. They can work in a chaotic, unreliable, and risky environment, adjust production parameters without requiring complete reprogramming and interact safely with others. Adopting such technology ensures increased operator safety, increased production efficiency, and a decrease in prices, times, and errors (Internet of Things, IoT) (Sony & Naik, 2020).

Internet of Things

Industry 4.0 is possible thanks to the Internet of Things (IoT), another fundamental idea (Forcina & Falcone, 2021). IoT is defined as the idea of extracting data from real-world devices and transmitting it across computer networks or fast wireless connections (Erboz, 2017). Integrating physical objects into the information technology network is the internet of things' primary goal. To do this, sensors must be integrated into real-world objects to provide simple communication (Bigliardi et al., 2020).

Cloud Computing

“Cloud computing” refers to any type of IT services provided and accessed by a cloud computing provider (Forcina & Falcone, 2021). The sorts of IT resources provided by cloud computing offers processing and storage capabilities by serving multiple users in a virtual system. Cloud computing has three types. One of them is platform as a service (PaaS), through which users, just like software developers, can have access to their applications on the cloud. The other one is software as a service (SaaS), which provides access according to customer purchases like ERP. Infrastructure as a Service (IaaS) offers its users the basic functions like storage capabilities (Erboz, 2017).

The Industry 4.0 business model that relies heavily on end-user devices, smart devices, and connected machinery to communicate data also requires immense computing resources to store, analyze, and share processed data with other devices, sensors, and embedded systems found throughout the supply chain. Only with cloud-based manufacturing, deployment of Industry 4.0 will be successful. It permits production to be more modular and service-oriented (Koh et al., 2019).

Big Data (BD) and Analytics

Collecting and analyzing large amounts of data available by employing the use of a series of techniques for filtering, capturing, and reporting insights between systems, along with an Industry 4.0 supply chain. There are four components of big data: data value, variety, velocity (speed of generating fresh data and analysis), and volume of data (Zheng et al., 2021). Design archives, inventories, supplier deliveries, customer orders, and logistics-related data are some of the sources of data. This enormous amount of data is described as big data. It is another critical idea in Industry 4.0. BD, CPSs, and the cloud can form an industrial network, and their coordination allows for the creation of a smart factory (Forcina & Falcone, 2021).

Simulation and the Digital Twin

Simulation is a term used to describe computer-based technologies that mimic actual processes or systems. For testing, optimization, and education purposes, it often refers to presentation or simulation of some important behaviors and characteristics of certain systems that can be abstract or physical. The production makes substantial use of product and process simulations, particularly those that involve visualization, representation, modeling, and interpretation. The accuracy of simulation findings is increased, and reality is brought closer by incorporating sensor data into computer simulations (Bravi & Murmura, 2021; Vaidya et al., 2018).

Digital twins become experiential digital twins (EDTs) when simulation techniques are used to give them life and make them practicable. Digital twin technology provides a platform for designing, testing, monitoring, diagnosing, forecasting, enhancing, and scaling up the lifetime of products and the production environment. A digital replica of a process or a physical object for their improvement can be made by digital twin technology using real-time data. By the use of the Internet of Things, AI, and software analysis, this technology primarily creates digital simulations of physical objects (Leng et al., 2021). Based on digital tracks created by artificial intelligence, one can reprogram physical items either by intervening in the digital twin or without doing so. People can use the activity traces left by digital technology to fix flaws or increase object modularity (Bai et al., 2020).

Virtual Reality and Augmented Reality (AR)

Virtual reality is commonly referred to as a three-dimensional (3D) world that is computer generated and simulates complicated contexts and circumstances in real life, enabling people to interact with, get immersed in, and navigate through it. Real-time interaction is an essential component of virtual reality. The technological equipment used in virtual reality consists of a computer, motion-sensor gloves, headphones, and an imaging helmet. To identify the view of users, their interaction with and navigation through the items, and the potential motion of their body (virtual body can be referred as "avatar") in virtual reality, VR systems typically track the motion of user's limbs and head, hand-held objects, and the received data. The core domains of VR applications include healthcare (Vrchota & Pech, 2019).

A system, known as augmented reality, links a virtual, computer-generated environment with the physical world in real-time, typically in the form of a picture. Although it can be utilized to simplify or disguise some aspects of reality, the effect that results from the overlap of these two pictures enhances the human experience (Machado et al., 2019). Augmented reality can be defined as an environment display that is interactive and is reality-based, enhancing the real-world experience by using computer-generated sounds, display and its other elements.

Mobile devices such as tablets, smartphones, braces, helmets, glasses, contact lenses, specialized equipment (head-up displays; HUD) and, in the future, virtual retinal displays too can be used to experience augmented reality. Despite being most commonly used in video games, Although video games are the most common use of augmented reality, it also has more significant applications in education, navigation, medical, commerce and construction sectors and in industrial design as well (Petrillo, De Felice, Cioffi, & Zomparelli, 2018).

Additive Manufacturing and 3D Printing

The process of printing actual products is referred as additive manufacturing while 3D printing is basically a group of additive or layered development frameworks that are used in additive manufacturing, to build three-dimensional (3D) solid objects through digital data flow (Erboz, 2017; Phuyal et al., 2020). 3D printing eliminates the first step of traditional production (preparing molds or dies, which are expensive and labor-intensive), decreasing expenses and considerably shortening the production cycle. In contrast to traditional production, which typically entails assembling and welding numerous components, digital design enables the production of goods with extremely complicated geometries from a single part. As a result, 3D-printed objects are stronger and last longer, and their designs are more flexible, which saves materials and makes customization easier and shipping cheaper, among other benefits (Yin et al., 2018).

Nanomaterials

Nanotechnology, which is now also known as molecular nanotechnology, is defined as the ability of manipulating specific molecules and atoms to create larger-scale objects. Nanomaterials are things or creations with very small dimensions, measured in nanometers. About one-millionth of a millimeter is a nanometer. They can be utilized in industry to create items that are light in weight and volume, exceedingly strong, are self-cleaning (able to remove dirt or bacteria from a surface) and self-healing materials, and are resistant to impacts imposed by external factors (such as car, aircraft, and other vehicle casings), They will prove to be very helpful in electronics because of their compact size, high electromagnetic impulse capacities , and electric conductivity (Pozzi, Rossi, & Secchi, 2021).

Block Chain

A block chain is a disseminated database which utilizes cutting-edge encryption and authentication technologies, along with a network-wide consensus procedure, to keep an exhaustive, disseminated, and unchangeable constantly growing list of information (Prisecaru, 2016). An openly circulated ledger which has the transactions between two parties directly, effectively, permanently, and verifiably recorded is referred to as a block chain. Additionally, a specific program can be used to automatically begin the transactions. The block chain has five fundamental features:

Distributed database: Users can have access to a database that is completely decentralized and keeps track of digital transactions. They can independently verify them despite of not being under their control.

Peer-to-peer transmission: This encompasses the direct communication between peer nodes (links) without a central node with each node storing and sending information to every other node.

Transparency with pseudonymization: Every system member has accessibility to all its transactions and is identified uniquely by an address that has than 30 characters. The transactions happen through these addresses.

Record irreversibility: Because each record is linked to the one before it by a string, a record cannot be modified, after the transaction data has into the system. There is a shortcut to the prior node in each node that comes after it.

Computational logic: Because transactions in the system can be coded and are subject to computational logic, participants can create algorithms and rules that permit seamless exchanges of data across nodes.

Block chain guarantees transaction security, lowers the chance of errors, forgeries, and hacking attempts, and dramatically lowers costs too by doing away with middlemen and hastening deployment. Currently, cryptocurrencies of which bitcoin is the most well-known are made via the block chain (Rymarczyk, 2020).

Cyber Security

Cybersecurity is the term for proactive measures used to guard against the theft, compromise, or attack of information. Technology in the field of cyber security tries to defend shared data against online attacks. The so-called "security by design" strategy, which entails establishing a system that is capable of taking security risks into consideration and, is based on a periodic assessment of choices made, is the best way to defend the business (Schumacher, Nemeth, & Sihn, 2019).

Other Technologies

RFID is a term used to describe technologies that automatically monitor and identify objects by communicating wirelessly which happens between an object (or tag) and an interrogating device (or reader) (L. D. Xu et al., 2018). A sensor is a piece of equipment that reacts to physical stimuli, like magnetic field, light, pressure, heat, sound, or specific motions, and transmits the resulting impulse for its use in measurement or controlling an appliance. A wireless communication technology integrated on a wireless device is known as “mobile technology” (Roblek et al., 2016).

The Global Positioning System (GPS) is a technological wonder. This technology enables the calculations and display of user’s information regarding speed, time, and location by GPS receivers. The collection of satellites revolving around the Earth's orbit in space have made possible this technology by transmitting precise signals. *Unmanned aerial vehicles (Drones)* are aircrafts that do not have a person as a pilot onboard are generally referred as drones (Bai et al., 2020).

2.2.2. Design Principles

The enabling technologies have the full potential to integrate and automate different business processes, people and machines, decentralized workflows, and digitalized production systems, which brings many benefits (Koh et al., 2019).

Following are the design principles or the characteristics of Industry 4.0:

Interoperability

The ability of a systems to communicate with, understand, and make use of the functions of each other is called interoperability. It depicts the capacity of the systems to share or exchange data, information, and knowledge with each other. Standardization and semantic descriptions are important since they imply that CPS, humans, and companies are connected by IoS and IoT (Hermann et al., 2016).

Virtualization

Virtualization is the capability of devices to monitor physical systems. It has an application in process monitoring communication and machine-to-machine. The sensor data creates a virtual copy of the physicals items as it is connected with both, the virtual plant model and with simulation models (Phuyal et al., 2020).

Decentralization

The ability of a firm's operations personnel and some devices to make independent decisions instead of being dependent on centralized decision-making is known as decentralization (Mohamed, 2018).

Real-time Capability

The systems can collect, analyze, and transmit data instantaneously. Continuous data analysis is required to react in real time to environment changes, for example handling errors or routing. This involves delegating authority, responsibility, and resources to lower levels of an organizational hierarchy. Employees can take decisions independently and pass decisions to higher tiers when failures or complex situations occur (Chauhan & Singh, 2019).

Service Orientation

The service-oriented architecture (SOA) is a software pattern in wherein application parts offer services to other components over a communication network, usually the network. This pattern allows for the encapsulation of different services to combine and make them more easily usable. Service orientation refers to the ability of devices to comply with the users' requirements over the internet. The notion of a product will encompass both the product and the product service because every component of the manufacturing chain is interconnected (Hermann et al., 2016).

Modularity

Modularity of a device or its components is their capability to be assembled, replaced, or upgraded as required in modular manufacturing system (S. Kumar et al., 2020).

2.2.3. Outcomes

These new technologies integrate information, people, and machines by creating more responsive and agile supply chains. Flexibility, efficiency, decentralization, integration, mass customization, increased productivity, the transformation of jobs and required skills, altered approaches to delivering products or services, etc. are some expected outcomes of Industry 4.0 (Li, Fast-Berglund, & Paulin, 2019). An organization vertical integration, (from product planning, manufacturing to final assembly) and horizontal integration (data sharing among customers, suppliers, and partners) both are essential elements of Industry 4.0. The outcome is a system in which all processes and operations are integrated and quick response to customer's demand change by sharing real-time data (Bravi & Murmura, 2021).

According to Schumacher, Erol, and Sihn (2016), "Industry 4.0" is used to describe businesses and sectors that use the internet and related technologies as the backbone for cross-organizational collaboration and the seamless integration of everything from physical items and smart equipment to human resources and manufacturing lines. Thus, a new class of networked, intelligent, and agile value chains is created. Businesses can increase the productivity and flexibility of their manufacturing thanks to this transition. These advancements enable businesses to more effectively satisfy customers' demands for mass customization (Genest & Gamache, 2020).

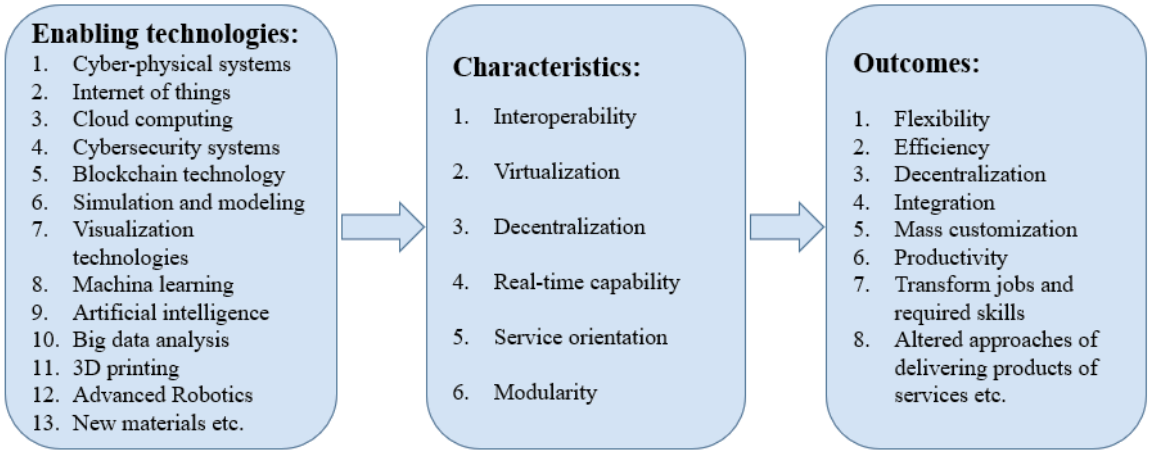

Figure 3: Industry 4.0 defining elements (Culot et al., 2020).

2.2.4. Industry 4.0 Readiness

The "readiness" for Industry 4.0 adoption refers to the extent to which a firm can benefit from the advanced technologies of Industry 4.0. In other respects, it shows the enterprise’s preparedness to adopt Industry 4.0's advanced technologies (Hizam-Hanafiah, Soomro, & Abdullah, 2020). The technology is the major enabler of Industry 4.0. In order to implement advanced technologies, present systems and infrastructure must be properly readied. For instance, a prerequisite for CPS is purposefully managing data and integrating numerous sensors and actuators into current production systems (Da Silva et al., 2020). Maturity is a contagious concept of readiness. It is possible to distinguish between readiness and maturity, as readiness is assessed before the actual implementation process starts while maturity is evaluated after implementation (Mittal, Khan, Romero, & Wuest, 2018).

2.2.5. Industry 4.0 Models

For better performance, researchers from industry and academia are continuously working on developing as well as re-developing the self-assessment models to evaluate firm’s readiness for Industry 4.0 adoption (Pacchini et al., 2019). These models are utilized to assess, characterize, and compare the current state of a firm with a desired state and identify potential feasible paths for organizational development (Wagire, Joshi, Rathore, & Jain, 2021). With these assessment models, businesses can look at the steps that lead up to the digital transformation process, which can change the organization (Sony & Naik, 2020).

The readiness assessment models measure the readiness of a firm in terms of resource levels (financial, human capital, expertise, capabilities, infrastructure, equipment, systems, etc.) and attitude across the organization. Conversely, maturity models specify a certain stage of growth within a scale range and describe the extent to which an individual or entity transforms (Schumacher et al., 2019). These assessment models could provide help to managers to benchmark and design roadmap for the successful implementation (Sony & Aithal, 2020). Hizam-Hanafiah et al. (2020) have thoroughly analyzed all dimensions of the existing thirty (30) Industry 4.0 models in the literature and identified the six most common dimensions of the Industry 4.0 readiness and maturity models. These six dimensions comprise; leadership, people, strategy, technology, innovation, and process. These six dimensions offer useful information, but they leave out several crucial ones that should be included for firm-level assessments and are regarded as crucial by some other frameworks.

Some model to assess the readiness of Industry 4.0 are discussed below.

IMPULS- Industry 4.0 Readiness Model

This model aimed to assess the organization’s readiness and capacity to implement the Industry 4.0 concept in the mechanical and plant engineering fields. It has six dimensions and six levels of maturity, each with a description. There is an online assessment option and there are 24 questions on the assessment survey. After the assessment, a thorough report is given with recommendations on how to raise each dimension's present level. The following are six dimensions in the model (Lichtblau, 2015; Schumacher et al., 2016):

1. Organization and Strategy
2. Employees
3. Data-driven services
4. Smart operations

5. Smart Products
6. Smart Factory

These six dimensions have further 18 associated categories and six levels, which include:

1. Outsider,
2. Beginner,
3. Intermediate,
4. Experienced,
5. Expert,
6. Top Performer.

This self-assessment tool consists of 26 questions and is available online. The model has a strong scientific foundation, and both its structure and findings are comprehensible (Amaral, Jorge, & Peças, 2019; Rajnai & Kocsis, 2018).

PwC Maturity Model

This model focuses on the organization's digitization and is designed for large organizations. The model has seven dimensions and have four maturity assessment levels. It is self-assessment tool that is available online, as well as it provide step wise guidance to develop Industry 4.0 implementation strategies and to take pilot initiatives (Dikhanbayeva, Shaikholla, Suleiman, & Turkyilmaz, 2020). This model is built around the seven following dimensions:

1. Digital business models & customer access,
2. Product and Service Digitization, ,
3. Data and analytics as a core capability
4. Vertical and horizontal value chains Integration and Digitization,
5. Digital culture, Organization and Employees,
6. Agile IT Architecture,
7. Compliance, Security, Legal & Tax.

It has four stages or levels:

1. Digital novice,
2. Vertical Integrator,
3. Horizontal collaborator,
4. Digital Champion.

This is also available online, and the questionnaire consists of 33 questions (Axmann & Harmoko; Rajnai & Kocsis, 2018).

Uni-Warwick Model

In partnership with Crimson & Co. and Pinsent Masons, Warwick University created this assessment tool. This assessment tool offer businesses an easy way to gauge both their current readiness and long-term goals in the age of digitalization. This model measure Industry 4.0 status in following six dimensions (Harmoko, 2020):

1. Product and service
2. Strategy and Organization
3. Manufacturing and operations
4. Business Model
5. Supply Chain
6. Legal considerations

This model has further 37 sub-dimensions or fields and have four assessment levels which are following:

1. Beginner,
2. Intermediate,
3. Experienced,
4. Expert.

No online questionnaire is available (Axmann & Harmoko; Rajnai & Kocsis, 2018).

Forrester's digital maturity assessment model

The Forrester's model assesses the firm's digital transformation in four dimensions.

1. Culture

   This dimension has items related to company leadership, vision, culture, innovation, strategy, employee's training, and education.

2. Organization

   This dimension includes items related to customer orientation, execution and governance of digital strategy, business processes, human resource, and organizational model.

3. Technology

   Technology dimension has items or fields related to investments, roadmaps, business value, flexibility, and developments driven by customers.

4. Insight

   This dimension has items related to KPI's to quantifiable measure the digital success by using customer's feedback.

Each dimension has subdimensions or items. This model has the following four levels.

1. Skeptics (0-33)
2. Adapters (34-52)
3. Collaborators (53-71)
4. Differentiators (72-84)

(Gill & VanBoskirk, 2016; Rajnai & Kocsis, 2018)

2.2.6. The proposed Industry 4.0 Readiness Assessment Framework

By thorough literature review and detail comparison of the above-outlined models, researcher designed a framework for the assessment of readiness for Industry 4.0 which entails five key determinants or dimensions, with further sub-dimensions. The main dimensions are, (1) Organization; (2) Smart Factory; (3) Smart Products and data-driven services; (4) Supply Chain; and (5) Legal Compliance, Security Risk, and Tax.

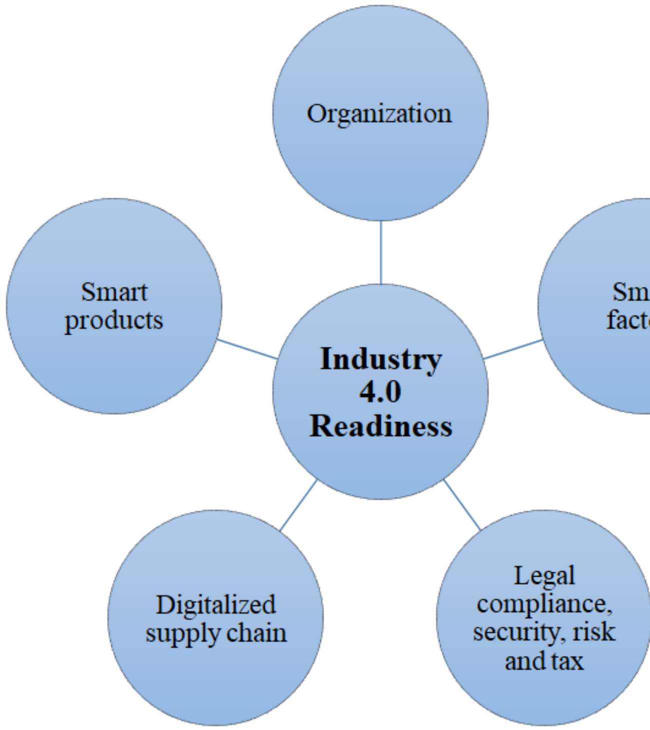

Figure 4: Schematic representation of Industry 4.0 readiness determinants.

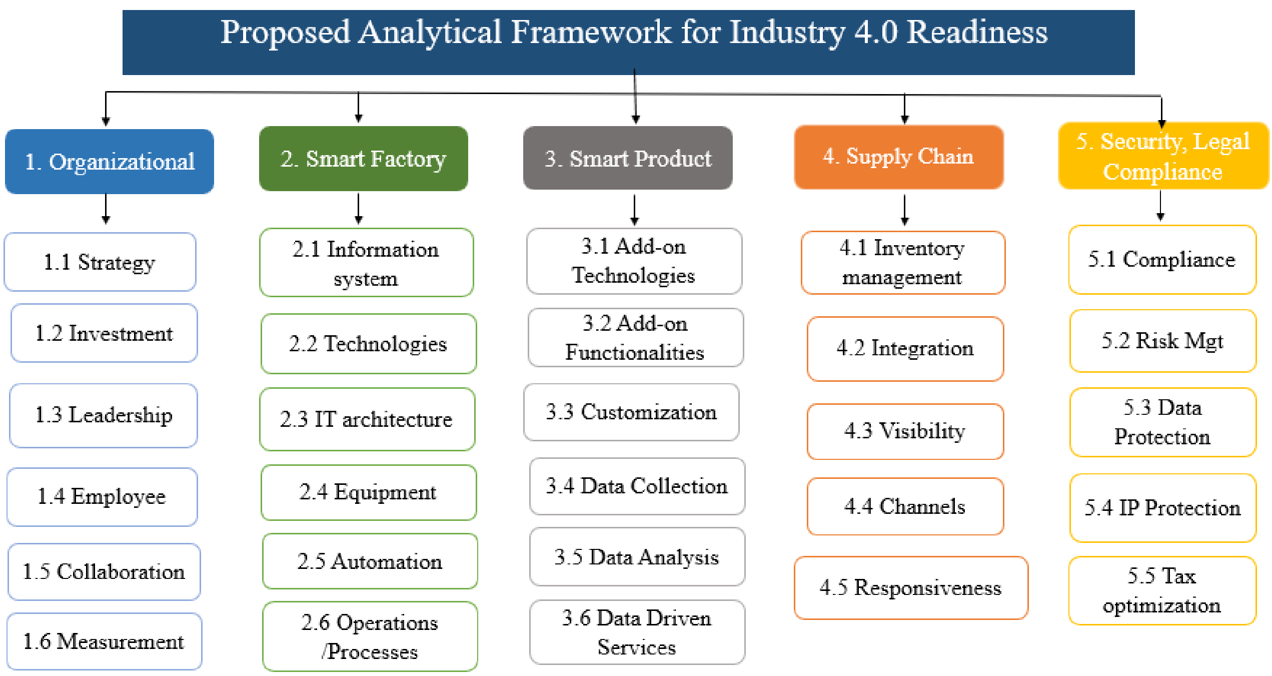

Figure 5: Proposed Analytical Framework for Industry 4.0 Readiness Assessment

Table 2*:* Comparison of Industry 4.0 Readiness Models Dimensions.

Dimensions	Proposed Framework	IMPULS	PwC Model	Uni-Warwick Model	Forrester Model
Organizational	1.1, 1.2, 1.3, 1.4, 1.5, 1.6	1.1, 1.4, 1.5, 1.6	1.3, 1.5	1.1, 1.3, 1.4, 1.5	1.1, 1.2, 1.3, 1.4, 1.5
Smart Factory	2.1, 2.2, 2.3, 2.4, 2.5, 2.6	2.1, 2.2, 2.3, 2.4	2.1, 2.3, 2.4, 2.5	2.4, 2.5, 2.6	2.3
Smart Product & data	3.1, 3.2, 3.3, 3.4, 3.5, 3.6	3.2, 3.4, 3.6, 3.5	3.1, 3.3, 3.4, 3.6	3.1, 3.3, 3.5	3.3, 3.5
Supply chain	4.1, 4.2, 4.3, 4.4, 4.5		4.2, 4.4	4.1, 4.2, 4.3, 4.5	4.4
Security, Legal Compliance	5.1, 5.2, 5.3, 5.4, 5.5	5.3, 5.5		5.1, 5.2, 5.3, 5.4	

2.2.7. Industry 4.0 Adoption Drivers

In general, a determinant is considered a driver when it encourages the adoption of Industry 4.0 technology. In contrast, when it works against adoption, it counts as a barrier. The five drivers have been narrowed down based on the literature review (Table 3).

Table 3: Industry 4.0 Adoption Drivers Review Chart.

Drivers							
Reference	**Financial**	**Customer requirement**	**Improve sustainability**	**Increase innovation**	**Increase productivity & efficiency**	**Legislation / standards**	**Competition**
Stentoft et al., 2021	✓	✓					
Vuksanvoic Herceg, Kuc, Mijuskovic, & Herceg, 2020	✓	✓	✓	✓	✓		✓
Ghobakhloo, (2020)		✓	✓		✓		
Calabrese, Ghiron, and Tiburzi (2020)	✓		✓	✓	✓		✓
Kumar, Singh, & Dwivedi, (2020)		✓		✓		✓	
Horvath, D., & Szabo, R.Z. (2019)	✓		✓	✓		✓	
Turkes et al., 2019		✓				✓	
Stentoft, Jensen, Philipsen, & Haug,2019	✓	✓	✓	✓			
Petrillo, De Felice, Cloffi, & Zomparelli, 2018	✓	✓			✓		
Slusarcyzk, 2018	✓	✓					
Hofmann & Rusch, 2017	✓	✓					
Pereira and Romero, 2017		✓				✓	
Zhou, Liu, & Zhou, 2015		✓					

The five shortlisted drivers are discussed below.

Financial (reduce costs)

To reduce the cost of operations, human resources, saving energy, inventory management, etc. (Stentoft, Adsbøll Wickstrøm, Philipsen, & Haug, 2021; Stentoft, Jensen, Philipsen, & Haug, 2019; Vuksanović Herceg, Kuč, Mijušković, & Herceg, 2020).

Customer Requirement

Customers from developed countries may require partner exporting companies to adopt Industry 4.0. For such firm, the Industry 4.0 adoption driver is to meet international customer demand to stay competitive and increase their share in foreign markets (Stentoft et al., 2021).

Improve Sustainability

Incorporating sustainability, i.e., economic, environmental, and social welfare aspects is a key driver for adopting Industry 4.0 for the many organizations.

Increase Innovation

Increase innovation is another important driver for adopting Industry 4.0. Firms could renew their value proposition, develop innovative products, new business models and redesign supply chain etc. (Stentoft et al., 2021).

Increase Productivity and Efficiency

It includes reducing errors and scrap ratio, shortening lead times (to meet customer demands), increasing efficiency, and making sure smooth operations i.e., reduce downtime (Stentoft et al., 2021). Efficiency improves by planning, automating physical tasks and information sharing (Pereira and Romero, 2017). The logistics industry is one that is seeing widespread adoption of automated technologies. For examples complete automation of warehouses, material, and pallet handling systems by using robots, tracking orders, and drones etc. reduces cost and maximize profitability.

2.2.8. Industry 4.0 Adoption Barriers

The manufacturing firms face several Industry 4.0 adoption barriers which hinder the implementation. From literature, six Industry 4.0 barriers are shortlisted (Figure 7).

Table 4: Industry 4.0 Adoption Barriers Review Chart.

Barriers								
Reference	**Organizational**	**Financial**	**Technological**	**Lack of Govt. Support**	**Security Risk**	**Legislation / standards**	**Public Advisor system**	**Risk of fragility**
Calabrese, Ghiron, and Tiburzi (2020)	✓	✓		✓	✓	✓	✓	
Kumar, Singh, & Dwivedi, (2020)	✓	✓	✓	✓	✓			
Ghobakhloo, (2020)		✓	✓		✓			
Schroeder et al., (2019)		✓	✓	✓	✓			✓
Sony & Naik (2019)	✓		✓					
Horvath, D., & Szabo, R.Z. (2019)	✓	✓						✓
Stentoft, Rajkumar, and Madsen (2017)	✓		✓		✓			
Calabrese, Ghiron, and Tiburzi (2020)					✓			
Peillon and Dubruc (2019)	✓		✓					
Geissbauer, Vedso, and Schrauf (2016)		✓						

The six shortlisted Industry 4.0 barriers are discussed below.

Organizational

Organizational barriers include a lack of an Industry 4.0-focused strategy, a lack of senior management expertise and support, a lack of employees' digital capabilities (skills, knowledge, and experience), an inadequate organizational structure, employee resistance, etc. (Hofmann & Rüsch, 2017; Stentoft et al., 2021). The industry may be hindered by top management's lack of leadership and support as well as their unclear vision regarding digital operations, applications, and their significance for the implementation of Industry 4.0 in the manufacturing sector (Petrillo et al., 2018).

Future production systems are predicted to undergo major changes due to the introduction of new technology and the redesign of business processes, necessitating the development of new skills among workers. As work organization becomes more flexible in time and space, it is expected that processes will be becoming increasingly visible and decentralized. Another critical hurdle to industry 4.0 is the shortage of expertise. There is the absence of internal training in the digital domain, company culture, and vision that along with a dearth of specialists also hinders the growth of Industry 4.0. Thus, the existing organizational culture and shortage of qualified workforce may hinder the implementation of Industry 4.0 (Türkeș et al., 2019).

Financial

The adoption of Industry 4.0 necessitates a sizable initial investment of financial resources. A key roadblock to the implementation of Industry 4.0 is a lack of funding. According to experts, SMEs still have trouble paying for the immense costs whether they are direct or indirect for acquiring Industry 4.0 technologies (Ghobakhloo, 2020). Despite claims to the contrary, some claim that SMEs can already afford and utilize Industry 4.0 technologies (Rauch, Dallasega, & Unterhofer, 2019). In order to acquire new technology, firms incur direct expenditures, which include things like the cost of the core systems, software, and hardware (Rezqianita & Ardi, 2020). Indirect costs include things like consultancy fees, cost of training programs, and maintenance fees that firms pay on a regularly basis to keep their technology running well. (R. Kumar, Singh, & Dwivedi, 2020).

To develop advanced infrastructure, sustainable processes, adopting Industry 4.0 poses significant financial obstacles. The Internet of Things (IoT) is the backbone of Industry 4.0, serving to connect all parties involved in the value generation process (Oks & Fritzsche, 2015). Although establishing an IoT network system necessitates investment in preexisting manufacturing infrastructure, doing so is seen as a necessary evil by those in the manufacturing sector, who consider it a major risk or barrier to the successful adoption of Industry 4.0 (Müller, Kiel, & Voigt, 2018).

Technological

The impediment is the complexity of Industry 4.0 technologies. A major obstacle to the broad adoption and usage of Industry 4.0 technologies is their complicated, integrative, and fragmented nature (Queiroz et al., 2019). The literature emphasizes how complicated technology hinders the adoption of augmented reality. Technological barriers include a low maturity level of technology in developing countries. There is absence of back-end systems for integration and a lack of commitment to cooperate (at the supply chain level) as well. The large amounts of storage capacity s also needed to cross the technological barrier for Industry 4.0 adoption (Ghobakhloo, 2020). The infrastructure used by the manufacturing sector needs to be upgraded to a smart infrastructure that integrates heterogeneous parts, tools, and techniques. But integrating these technologies and tools may not be possible due to their infrastructure, (Zhou, Liu, & Zhou, 2015).

Lack of Govt Support

Government support hurdles include a lack of Govt. initiatives, policies, standards, rules, and regulations, as well as a lack of ICT infrastructure. In most countries, an infrastructure is needed for the digitalization e.g. the internet and communication systems. It is supported by the government. However, guidelines to transform industrial infrastructure is lacking, partly because it is unclear what has to be done (e.g., 5G network development). Industry 4.0 development is hampered by the absence of working procedures and laws in developing nations, and lack of legislation governing the growth of cloud computing, cyber security, augmented reality, and artificial intelligence (Türkeș et al., 2019).

Lack of Clarity regarding the Economic Benefit

Another hurdle to Industry 4.0 adoption is the lack of clarity surrounding the accurate assessment of the economic benefits as well as the profitability and return on investment of new technologies. The manufacturing sector has to invest heavily in infrastructure to adopt Industry 4.0 (Horváth & Szabó, 2019). However, they have not yet developed solid business cases that would support this significant expenditure. The application of Industry 4.0 faces a critical problem due to unclear cost-benefit analysis and financial gains on digital investments (Stentoft et al., 2019).

Risk of Security

Some of the security risk barriers include unsafe data storage systems, risks of information sharing with business partners, fear of data loss to third parties and other cyber security issues, etc. With the Internet of Things (IoT), Industry 4.0 may function in real time, and there will be a constant, massive exchange of data and knowledge. There could be sensitive client and business information. The fear of data leakage is a threat for businesses. So, security risk is a barrier for the adoption of Industry 4.0 (Stentoft et al., 2019).

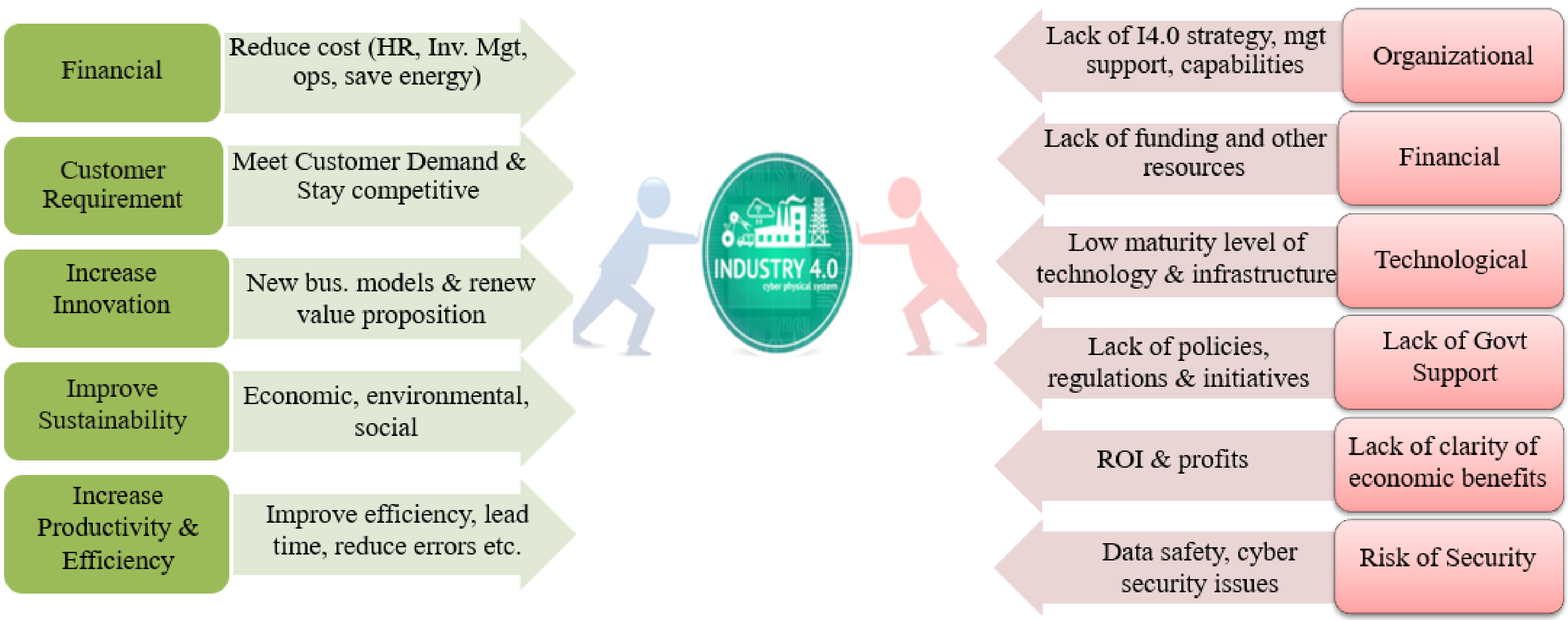

Figure 6: Industry 4.0 Adoption Drivers and Barriers.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter highlights the study's research design that forms the basis of this research. It elaborates on how the investigation is planned and structured by discussing the design and strategy adopted for this research. The sampling technique used to develop the questionnaire, along with the items of the variables used in this study, is explained comprehensively. Furthermore, the participants and the procedure considered in this study are mentioned in detail.

This research has two studies; the first study analyzed the readiness of manufacturing firms for adopting Industry 4.0 in Pakistan, and the second study investigated the Industry 4.0 adoption drivers and barriers. In the second study, a pairwise comparison was made for each driver and barrier to rank them through the Analytical Hierarchy Process (AHP) technique. The research design for both studies is discussed one by one in this chapter.

3.0. Research Design and Strategy

The research design is the conceptual blueprint that provides the roadmap for the research. Its major objective is to develop a plan and structure for the research study that can increase its validity (Sekaran & Bougie, 2016). In general, qualitative and quantitative are the two important research designs used for research purposes (Bell, Bryman, & Harley, 2022). Qualitative research design has categories, e.g., phenomenology, case study, grounded theory, historical, narrative, and ethnography design. In contrast, quantitative research design includes experimental and nonexperimental designs. The non-experimental design includes descriptive, comparative descriptive, and correlation design (Siedlecki, 2020).

3.1. Research Design for study 1

The first study has a quantitative descriptive research design. Quantitative research uses statistical procedures to empirically study the phenomenon of interest (Antwi & Hamza, 2015). Furthermore, the descriptive study describes individuals, conditions, or events by examining them as they are in nature. It describes the sample and/or variables without manipulating them. It can look into several variables, but it is the only research design to explore a single variable. It produces hypotheses rather than testing them. Hence, descriptive research has specified objectives and research questions instead of hypotheses. There are no dependent nor independent variables, rather only variables of interest. Descriptive research uses observational or survey data (Siedlecki, 2020). For the first study, survey data is used to assess the readiness of manufacturing firms for Industry 4.0 adoption. The survey method helps to gather data from a larger group of people; it has the advantages of generalizability, reliability, versatility, and cost-effectiveness (Bell et al., 2022).

3.1.1. Participants & Data Collection Procedure

Population

In the first study, manufacturing firms in Pakistan were targeted. The targeted firms came from a wide spectrum of manufacturing subsectors or industries, such as:

(a) Automotive and automotive accessories

(b) Chemical and Allied Industry

(c) Electronic and Electrical Equipment Industry

(d) Food and Beverage Industry

(e) Leather Industry

(f) Mechanical Machinery

(g) Metal Products

(h) Rubber and Miscellaneous Plastics Industry

(i) Surgical Instrument Industry

(j) Textile Industry

(k) And other….

The target firms included in the survey were small, medium, and large organizations from different geographical locations. These population characteristics make this study interesting and very important as it concerns evaluating the readiness of Industry 4.0 in the overall manufacturing sector. Moreover, only one response is considered from a firm, and only those responses are included that fulfill the criteria as respondents must be practitioners from the manufacturing sector of Pakistan.

Sampling Technique

A convenient non-probability sampling technique is used to collect data based on time constraints, cost, and other resource requirements. A convenience sample can be selected from an easily available source to the researcher (Andrade, 2021). For the first study, non-probability sampling is adopted because all participant firms were not selected on a random basis. The researcher sought responses from manufacturing firms all over the country. For this purpose, the researcher approached the "**Federation of Pakistan Chambers of Commerce and Industry" (**FPCCI) to distribute an online survey all over Pakistan. The FPCCI has 246 trade bodies. Moreover, researchers contacted many chambers of commerce and trade associations directly, used the department Industrial Linkage Office (ILO) platform, personal contacts, and physical visits to the industries to circulate surveys and collect data.

An anonymous online questionnaire was designed and distributed through email to different middle managers or high-ups in Pakistan's manufacturing industries to collect data. The survey was required to be filled out by someone who has a complete view of the business context and works as a C-level executive, executive, director, senior manager, and manager. The first study's questionnaire was self-administered; participants were advised to contact the researcher if they had any difficulty in understanding the statements asked in the questions. Two reminders were sent between 15 and 20 days to remind respondents to complete the survey. For the first study, a sample size of 130 was achieved.

3.1.2. Research Instrument for study 1

For the first study, a structured web-based survey was designed on "Google Forms" for data collection. For developing the questionnaire, a framework for assessing Industry 4.0 readiness was proposed by comparing some existing readiness self-assessment models, such as IMPULS, the PCW Model, the Uni-Warwick Model, and the Forrester Model. In the questionnaire, items were adapted from the models as mentioned above. In addition, the questionnaire also contained questions related to demographics.

The survey has closed-ended questions (please see Annexes A) to assess the readiness of manufacturing firms for Industry 4.0 adoption. It used multiple choice questions (MCQs) to obtain general information in section 'A'. Section 'B' used MCQS in a few items, and the rest of the items were assessed on a scale of 1–4. Veza, Mladineo, and Peko (2015) used the same scale in the survey to analyze Croatian firms' level of Industry 4.0 adoption. The 1-4 scale provided better pilot research results than 1–5 for determining the deployment of various technologies in manufacturing firms. (Vrchota & Pech, 2019). Respondents were requested to choose from the pre-defined options provided against every statement. Items under a 1-4 scale ask the respondents how much they agree with the statement. Where '1= strongly disagree, 2=disagree, 3=agree and 4=strongly agree. Respondents were asked to provide general information in section A about the company of employment, location, designation, type of company, sector, and size. The questionnaire focused on the main five dimensions of Industry 4.0 implementation: organization, smart factory, smart products & data-driven services, digital supply chain, and security and compliance.

The context of survey components in five dimensions is discussed below.

Organization

In this section, questions are included that are relevant to organization strategy, investment, leadership support, employee skills, collaboration, and measurement related to Industry 4.0. These questions measure overall organizational readiness for the implementation of Industry 4.0. In the questionnaire, items 8-10 and 14-20 assess the organizational readiness of manufacturing firms for Industry 4.0 adoption.

Smart Factory

Questions in this section are related to technologies, information systems being used in organizations, IT architecture, equipment, operations, and processes. In the questionnaire, items 11,12, and 21 to 29 assess the readiness of manufacturing firms for the smart factory.

Smart Products and Data-Driven Services

Statements in this section are related to product add-on functionalities and technologies and statements related to data collection, analysis, and usage. In the questionnaire, items from 30 to 37 assess the readiness of manufacturing firms for smart products and data-driven services.

Supply Chain

Statements in this section are related to real-time inventory management, integration, visibility, responsiveness, sales force, etc. In the questionnaire, items 38-44 assess the readiness of the digital supply chain of manufacturing firms for Industry 4.0 adoption.

Compliance, Legal, Risk, Security & Tax

Statements in this section are related to compliance policy, data protection, risk, IP protection, tax, etc. In the questionnaire, items from 45 to 51 assess the readiness of compliance, legal, risk & tax of manufacturing firms for Industry 4.0 adoption.

3.1.3. Analytical Procedure

Data Screening

An online questionnaire was designed in which all fields were required to fill in from the given options. So, no outliers and missing values were present in the online survey. But in hard copies of the survey, researcher treated all missing values**.**

Data Analysis

For the first study, a statistical tool, i.e., Microsoft Excel is used to analyze data to assess the firms' readiness level.

The workflow of the first study from start to end is illustrated below.

Workflow of Study 1

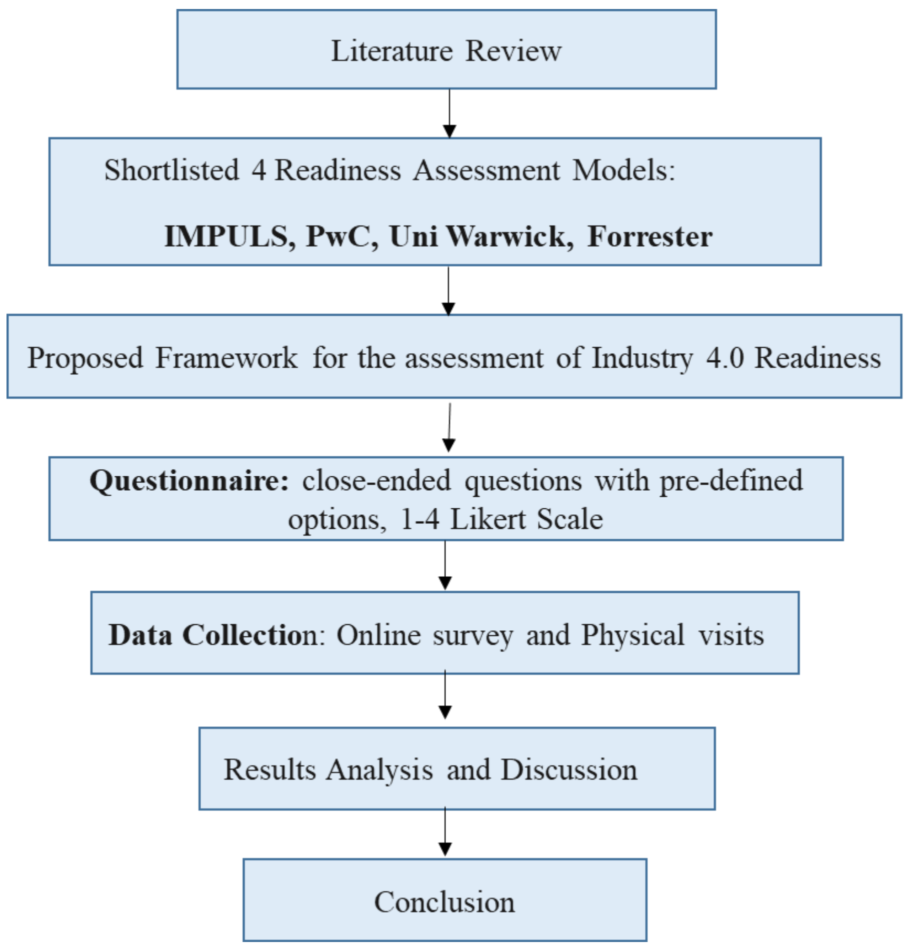

Figure 7: Workflow Chart of Study 1.

3.2. Research Design and Strategy for Study 2

In the second study, the Industry 4.0 adoption drivers and barriers for manufacturing firms are identified through a comprehensive literature review and shortlisted them with the help of experts from academia and industry in Pakistan.

Concerning the time horizon of the study, a cross-sectional study design was used, meaning that data collected for the analysis was gathered at a specific point in time.

3.2.1. Participants & Data Collection Procedure

Population

Study 2 also targeted the manufacturing sector of Pakistan. The large-scale manufacturing sectors, i.e., Textile, Automotive & automotive accessories, and the Chemicals Industry, were identified as appropriate for conducting the second study. The industry experts were selected from large organizations from different parts of the country.

Sampling Technique

A non-probability purposive sampling technique is used to collect data for study 2 based on time constraints, cost, and other resource requirements. A purposive sample is one in which characteristics are defined for a specific purpose pertinent to the research (Andrade, 2021). In the purposive sampling technique, the selection of participants (industry experts) is based on the researcher's judgment (Bell et al., 2022). Using this criterion, the industry experts chosen were practitioners from the manufacturing sector of Pakistan with more than ten years of experience in the industry. They were from top management and had a complete view of the business context. Seven industry experts were interviewed, i.e., four from the textile sector, two from the automotive sector, and one from the chemical industry.

3.2.2. Research Instrument for study 2

A list of Industry 4.0 adoption drivers and barriers was identified and shortlisted through a comprehensive literature review to design a survey matrix. The survey aims to compare each driver and barrier pairwise to evaluate and rank them in the Pakistan manufacturing sector. There are five drivers and six barriers included in the survey. Industry 4.0 adoption drivers include financial (reducing cost), customer requirements, increasing innovation, improving sustainability, and increasing productivity and efficiency. While Industry 4.0 barriers include organizational, financial, and technological ones; lack of Govt support, lack of clarity regarding economic benefits; and security risks. Please see Annex B for the survey.

3.2.3. Analytical Procedure

Data Screening

For the second study, researchers were presented in the interview to fill out the survey and ensure no missing value or outlier was present in the data. Interviews were recorded with the consent of the industry experts to evaluate their opinions.

Data Analysis

The Analytical Hierarchical Process (AHP) technique is used to prioritize drivers and barriers. AHP is a multicriteria decision-making (MCDM) technique which is used to make choices when several objectives are at stake. Saaty created the AHP method in 1980 (Saaty & Vargas, 1980) to address challenging decision-making issues. Any complex decision-making problem can be broken into multiple levels of subproblems using the AHP technique, where each level displays a set of criteria or qualities pertinent to the subproblem. AHP develops the hierarchy and prioritizes among the criteria or attributes using the pairwise comparison method.

Workflow of second study from start to end is shown below.

Study 2 Workflow

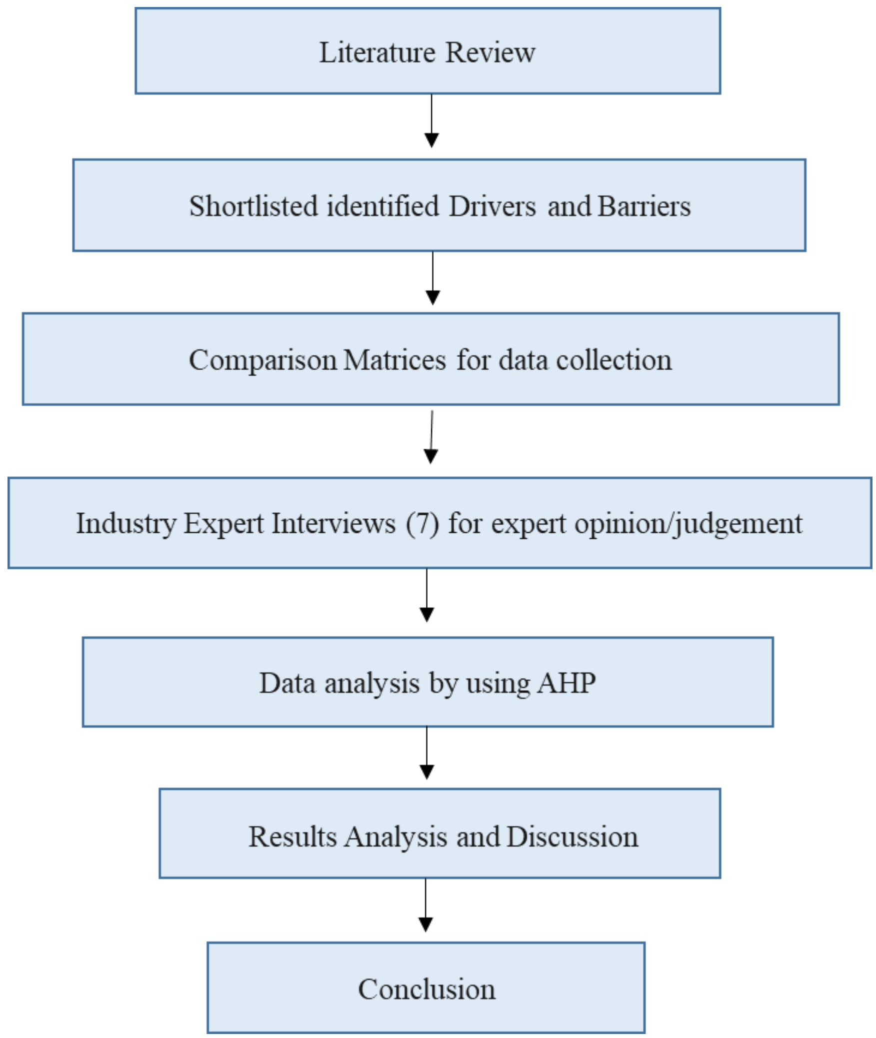

Figure 8: Workflow Chart of Study 2.

CHAPTER 4: STUDY 1

RESULTS AND DISCUSSION

4.1. First Study Results

This chapter presents the findings of the first study. The first study aimed to assess the readiness of manufacturing firms for the adoption of Industry 4.0, and for that purpose, data collection was done via a questionnaire-based survey. The chapter initially states the sample's descriptive statistics and the respondents' demographic attributes.

4.1.1. Sample Descriptive:

Section A of the questionnaire comprised of seven questions, and the set of information asked in the first part was related to demographics, i.e., the company of employment, location of the company, designation, type of company, type of sector, and size of the company. The data set for the first study was gathered from the people working in the manufacturing sector of Pakistan. The respondents targeted were mainly from top and middle levels and were not part of the lower management of the firms. Unfortunately, the response rate was very low, and total of 130 responses were obtained from the respondent firms. Out of a total of 130 responses, 82 responses are included in the results and discussion. While 48 responses are discarded on the following basis:

1. Duplicate responses
2. Not from Pakistan
3. No investment / Low investment (less than 5 million)
4. Non-manufacturing firms
5. Unengaged Responses

The results of the sample descriptive are discussed below.

The sample is composed of 55% large size, and 45% small & medium size firms (Figure 9).

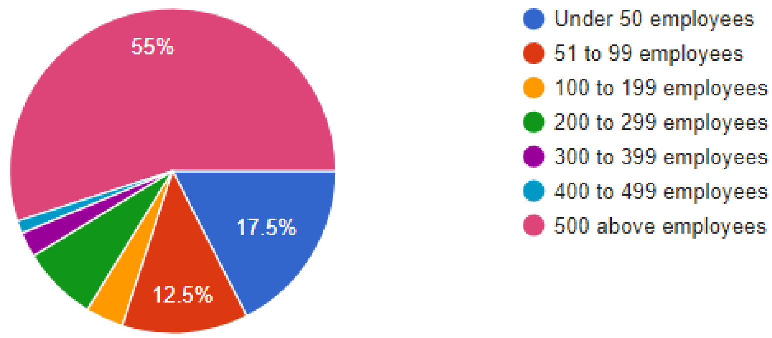

Figure 9: Size of the surveyed manufacturing firms

76.3% sample represent private limited firms, 6.3% public limited, 6.3% multi-corporation, 2.5% proprietorship, and 8.5% others (Figure 10).

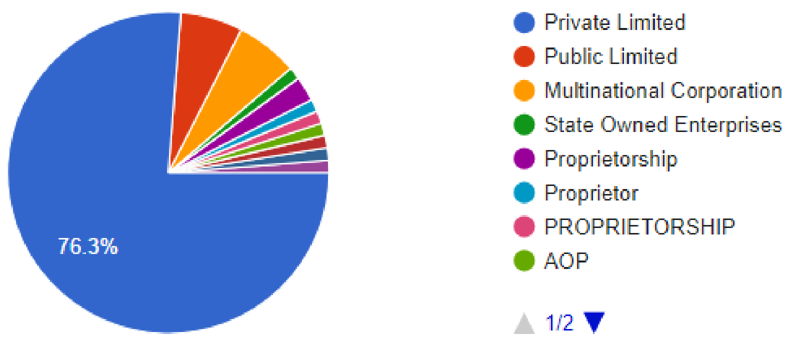

Figure 10: Types of the surveyed manufacturing firms

47.4% sample represent Textile sector, 6.6% Rubber, and Miscellaneous Plastic Industry, 5.3% automotive and automotive accessories sector, 5.3% metal products, 3.9% Chemical and allied industry, 3.9% Food and Beverages industry, 3.9% Pharmaceutical, 2.6% Mechanical Machinery and 21.1% other (Electronic and electrical, leather, surgical instruments, stainless steel, cement industry, etc.). 46.4% of respondents were from top management (C-level executive, General manager, directors, etc.), 51.2% were managers, and 2.4% were assistant managers (Figure 11).

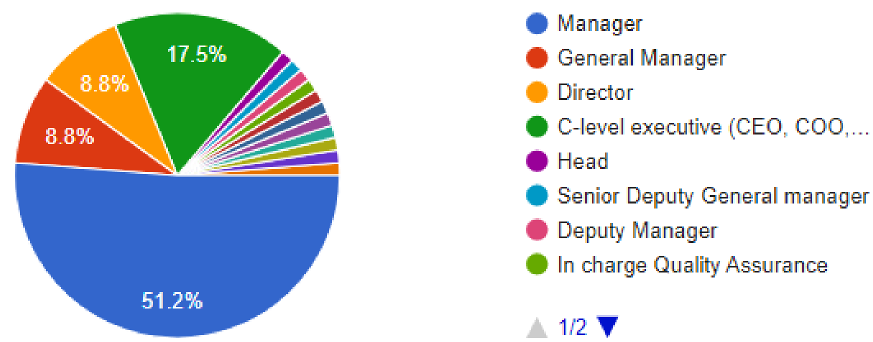

Figure 11: Designations of respondents.

4.2. Survey results

Section B of the survey entails 44 items that ask questions in five dimensions of Industry 4.0 implementation, i.e., (organization, smart factory, smart product & data-driven services, digital supply chain, compliance, security, and tax).

4.2.0. Readiness Levels

The Industry 4.0 readiness is not an abrupt transformation; rather, it is a gradual transition which includes a numerous stages/levels (Maisiri & Van Dyk, 2019). In this study, the Industry 4.0 readiness assessment tool seeks to analyze a firm's stage of readiness in relation with digital transformation. The assessment tool measures the readiness level of firm in five Industry 4.0 adoption dimensions (organization, smart factory, smart product, digitalized supply chain and security, risk, & tax) by using a set criterion of four readiness levels. The level of readiness is determined by calculating overall average of five dimensions of responses which are on scale 1-4. The four readiness levels to which a firm can belong are following:

Level 1: (average =< 1)

Firms at this level has no knowledge about Industry 4.0 and is not ready at all to adopt it.

Level 2: (average >1, =< 2)

This is the most basic or lowest level of readiness. Firms at this level have a little knowledge about Industry 4.0 and associated technologies. But no investment and practical steps toward its adoption.

Level 3: (average >2, =< 3)

This level indicates that firms are somewhat ready to adopt Industry 4.0. They are aware of Industry 4.0 concept, its advanced technologies, and potential benefits. They have made some investments and taking steps towards Industry 4.0 adoption.

Level 4: (average >3, =< 4)

This is the highest level of readiness which shows that a firm is fully prepared to adopt Industry 4.0. At this level firms have made large investments in Industry 4.0 technologies. They actively implementing Industry 4.0 strategy and refining its processes.

4.2.1. Overall readiness

The overall readiness level of 82 manufacturing firms for all five organization dimensions for Industry 4.0 adoption indicates that 3 manufacturing firms are at readiness level 1, 30 are at readiness level 2, 39 are at readiness level 3, and 10 are at level 4 (Table 5). Most of the manufacturing firms are between level 2 and level 3. That means Pakistan's manufacturing sector is not prepared to adopt Industry 4.0.

This result is expected in a developing country like Pakistan with few resources. There is a lack of comprehensive government policy and efforts to promote Industry 4.0 adoption initiatives and culture in the country. In such country like Pakistan, digitalization programs are typically launched at the organizational level by individuals who have not fully comprehend the concept of Industry 4.0. They are unaware of the organizational and structural changes required to adopt Industry 4.0. Instead, a few firms which go for digitalization invest in and deploy some of the Industry 4.0 technologies that are consistent with their businesses, require minimum expenditure, and have a naive technological infrastructure. This is one of the main reasons due to which firms in developing countries like Pakistan lag to be fully prepared to adopt Industry 4.0 effectively. Industry 4.0 readiness extends beyond just investing in advanced technologies such as addressing issues related to organizational strategy, human resource skills and capabilities etc.

Table 5. Overall Industry 4.0 Readiness Level.

I4.0 Readiness Level	Organizational		Smart Factory		Smart Product		Supply Chain		Risk & Legal		Overall Readiness	
	No. Firms	%	No. Firms	%	No. Firms	%	No. Firms	%	No. Firms	%	No. Firms	**%**
Level 1: Not ready at all, no knowledge	3	4%	8	10%	7	9%	8	10%	7	9%	3	4%
Level 2: Little knowledge but no steps toward I4.0 adoption	17	21%	38	46%	31	38 %	28	34%	32	39%	30	37%
Level 3: Somewhat ready, some investments to adopt I4.0	49	60%	30	37%	37	45 %	35	43%	28	34%	39	48%
Level 4: Ready to adopt, large investment	13	16%	6	7%	7	9%	11	13%	15	18%	10	12%
Total no. of firms	82		82		82		82		82		82	

The results are somewhat similar to Tripathi and Gupta (2021) study, which evaluates the Industry 4.0 readiness of 126 countries, representing 98.25% of the total national income of the world. Findings indicate that many countries lack essential capabilities for Industry 4.0 transformation: 72 countries perform below average on the enabling environment dimension, while 64 countries lack skilled human resources, 67 lack suitable infrastructure, 80 have poor innovation capabilities, 66 are below average on the cybersecurity infrastructure dimension, and 69 are below the ecological sustainability mean score.

Shqair and Altarazi (2022) have similar findings, showing that SMEs in Jordan are neither mature nor prepared to adopt Industry 4.0. Regarding the readiness dimension, SME survey participants and experts concurred that the status of Jordanian SMEs is between having initiatives in the pilot phase and implementing concepts to low degrees, except for smart products and autonomous workpieces, in which SMEs in Jordan lag due to financial and technological constraints. Rakic, Pavlovic, and Marjanovic (2021) study argued based on its results that Serbian manufacturing firms' overall readiness changed from non-users in 2015 to basic readiness in 2018. Similar results have been found Tortora et al. (2021) by using a web-based survey, which highlighted that firms still have scant knowledge of Industry 4.0 and are not fully ready to adopt it. According to Machado et al. (2019) study, most Swedish manufacturing firms analyzed are at the same initial readiness level as the manufacturing firms of Germany, i.e., taking the initial steps towards digitalization, facing the same problems, and lack of knowledge is still a significant barrier.

4.2.2. Organizational Readiness

The questionnaire contains ten questions assessing an organization's readiness for Industry 4.0 adoption. These questions were about organizational strategy, investment, leadership, employees, collaboration, and measurement related to Industry 4.0. The survey results show that out of a total of 82 firms, 3 (4%) firms are at level 1, 17 (21%) firms are at level 2, 49 (60%) firms are at level 3, and 13 (16%) are at level 4 (Table 5; Figure 12). So, it can be concluded that firms are not well prepared at the organizational level to adopt Industry 4.0. Further, some results of the organizational dimension are discussed.

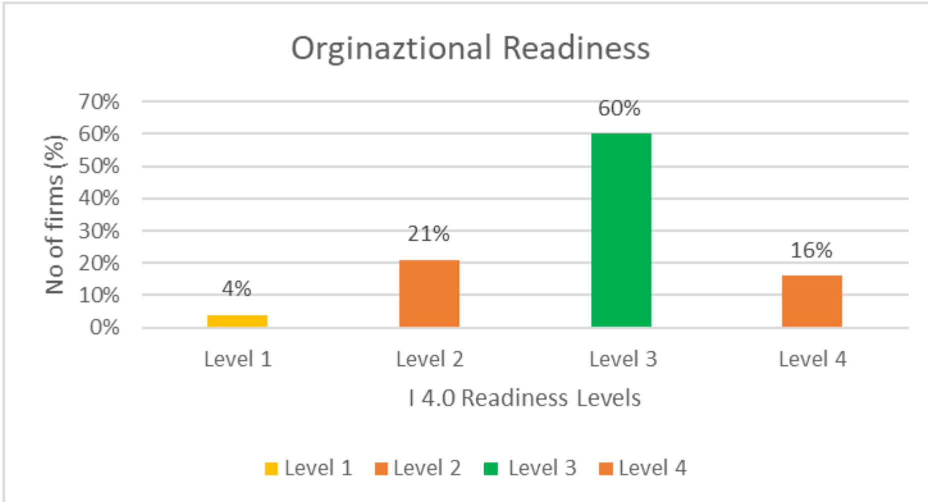

Figure 12: Organizational Readiness Level.

Industry 4.0 strategy

Survey results indicate that the strategy for Industry 4.0 is neither clearly defined nor shared with employees. Only 1.2% of firms have implemented the Industry 4.0 related strategy, while 35% have not yet devised a strategy for Industry 4.0 adoption, and 8.8% are not planning to invest in Industry 4.0. (Figure 13). The results are aligned with the Machado et al. (2019) findings, which state that there is a lack of Industry 4.0 strategies among many Jordanian SMEs.

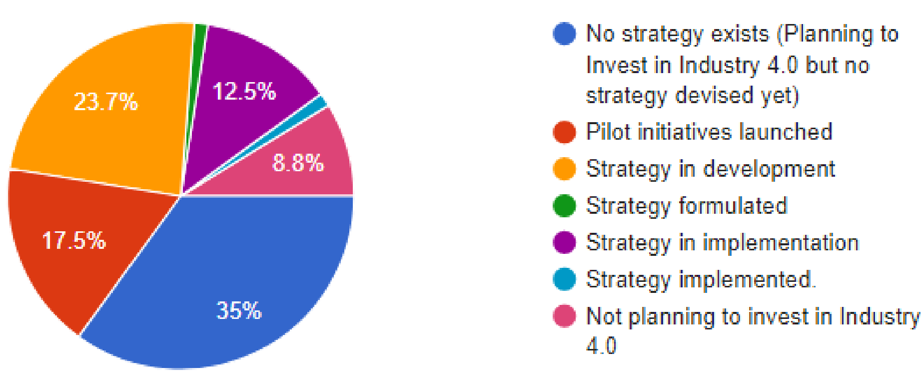

Figure 13: Status of Industry 4.0 strategy implementation.

Firm's investment in Industry 4.0

In terms of investment in Industry 4.0, only 36.8% of surveyed firms have no investment in Industry 4.0. 7.9% of firms have invested under 1 million PKR, and 10.5% of firms' investments are between 1 million to under 5 million PKR. Only 22.4% of firms have invested above 50 million PKR, 7.9% of firms have invested between 10 million to under 20 million PKR and 9.2% of firms have invested between 5 million to under 10 million PKR (Figure 14). These numbers are deficient and show that overall awareness of industry 4.0 is not high in Pakistan.

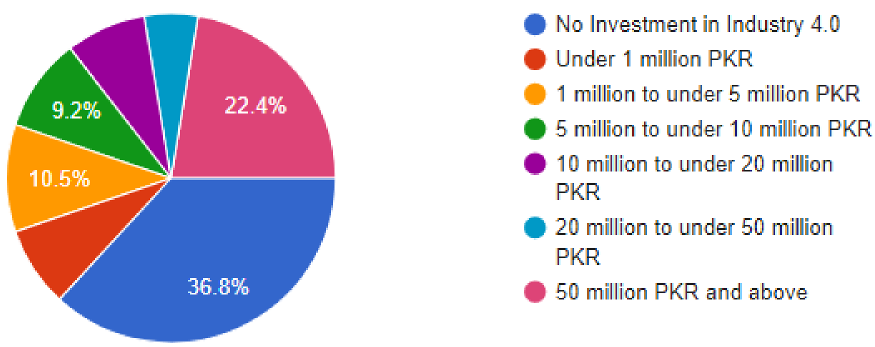

Figure 14: Investment in Implementation of Industry 4.0.

13.8% of firms' employees are at level 1, meaning they do not know about Industry 4.0. 40% of firms' employees are at level 2, which means they have very less knowledge about Industry 4.0. 42.5% of firms' employees are at level 3, which shows they have little knowledge and understanding of Industry 4.0. And only 3.8% of firms' employees have well understood and have skills related to Industry 4.0 (Figure 15). This suggests that firms should focus more efforts to identify internal competencies, on training, and supporting strategic hiring practices.

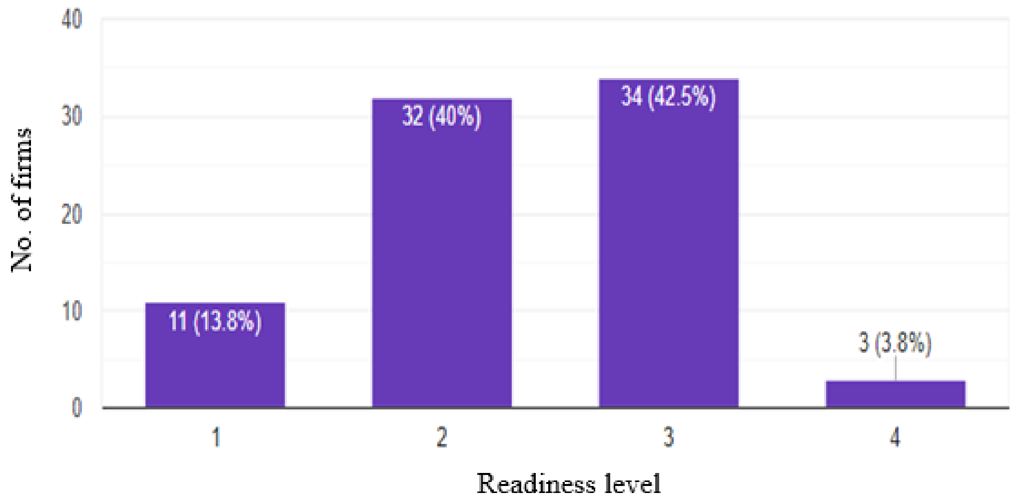

Figure 15: Level of employee's digital capabilities and experience.

Smart Factory

The distribution of smart factory readiness level firms is as follows: 8 (10%) firms are at level 1, 38 (46%), 30 (37%), and 6 (7%) firms are at level 4 (Figure 16).

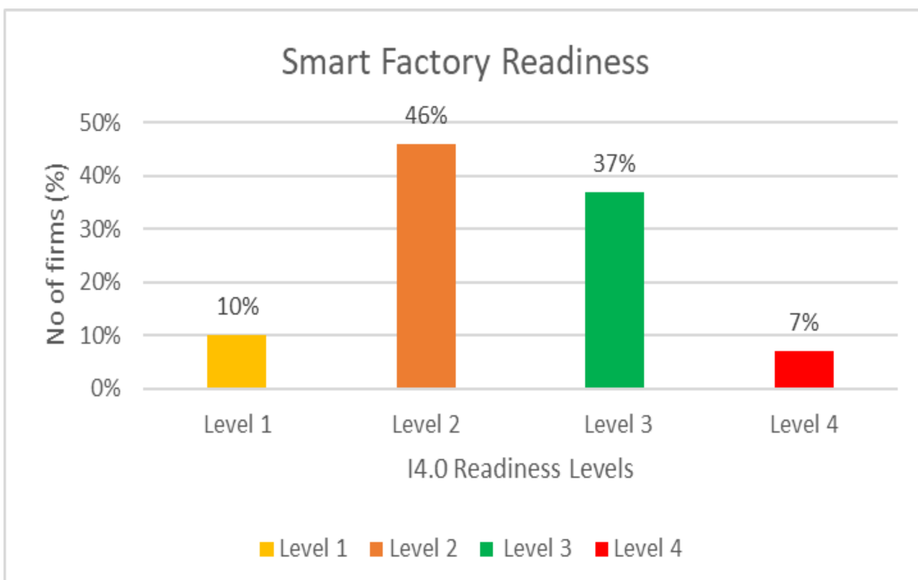

Figure 16: Smart Factory Readiness Level.

The Shqair and Altarazi (2022) study has similar findings, indicating that the smart factory dimension is not widely employed in practice. The autonomous workpiece dimensions have the lowest degrees of readiness. This might be ascribed to the fact that the information technology (IT) infrastructure is not developed enough to support CPS, IoT, and interoperability, which are important components of the advanced IT infrastructure needed to have efficient digital data systems. This could be because smart technology is expensive and hard to set up. When it comes to having smart equipment infrastructure (e.g., IT-controlled machines and systems, machine-to-machine communications), most surveyed firms lack such infrastructure. The cost factor is one possible reason for preferring the human workforce over smart equipment. In developing countries like Pakistan, firms don't think it's worth investing in smart equipment because labor costs are low, and customer demands about quality are not so high.

Smart product:

The smart products have smart add-on functionalities (e.g., automatic identification, product memory, self-reporting). The results for smart product and data-driven service readiness show that 7 (9%) firms are at level 1, 31 (38%) firms are at level 2, 37 (45%) firms are at level 3, and 7 (9%) firms are at level 4. (Figure 17; Table 5)

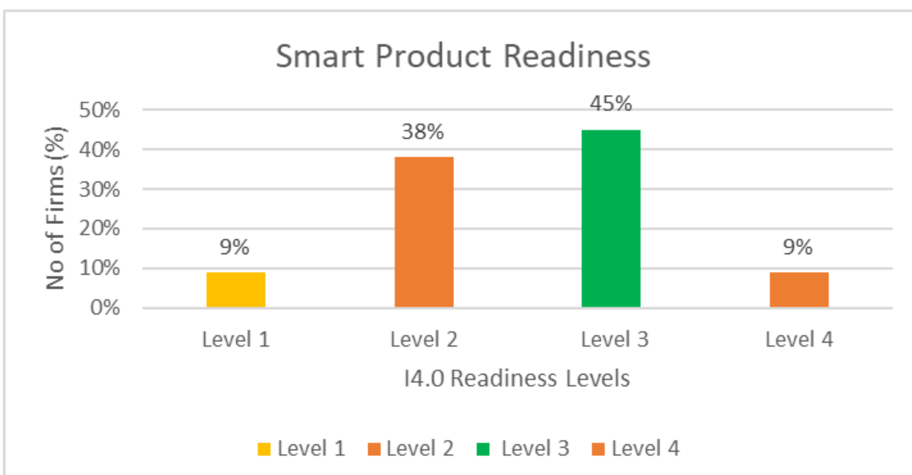

Figure 17: Smart Product Readiness Level.

Most surveyed firms reported that their products do not have add-on functionalities. It is quite rare for country like Pakistan to have access to smart products, which are seen as cutting-edge in the context of Industry 4.0. Digital data collection systems involving smart data collection, storage, and processing are prerequisites for Industry 4.0 adoption, ensuring efficient resource use. Findings show that many firms do not have such digital systems in place to collect processes and machine data throughout the manufacturing process.

Digital Supply Chain Readiness

The firm's supply chain readiness level is that 8 (10%) firms are at level 1, 28 (34%) are at level 2, 35 (43%) are at level 3, and 11 (13%) firms are at level 4 (Figure 18; Table 5). These results indicate that most surveyed firms have not yet digitalized their supply chain, which is important to integrate with suppliers, distributors, and customers.

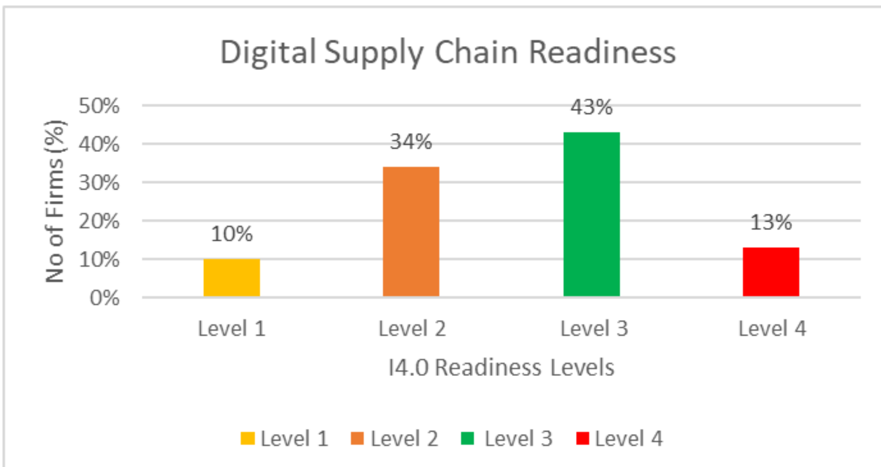

Figure 18: Digital Supply Chain Readiness Level.

Legal compliance, Security, Tax Readiness

The legal compliance and security tax readiness are that 7 (9%) firms are at level 1, 32 (39%) are at level 2, 28 (34%) firms are at level 3, and 15 (1%) firms are at level 4. (Figure 119; Table 5).

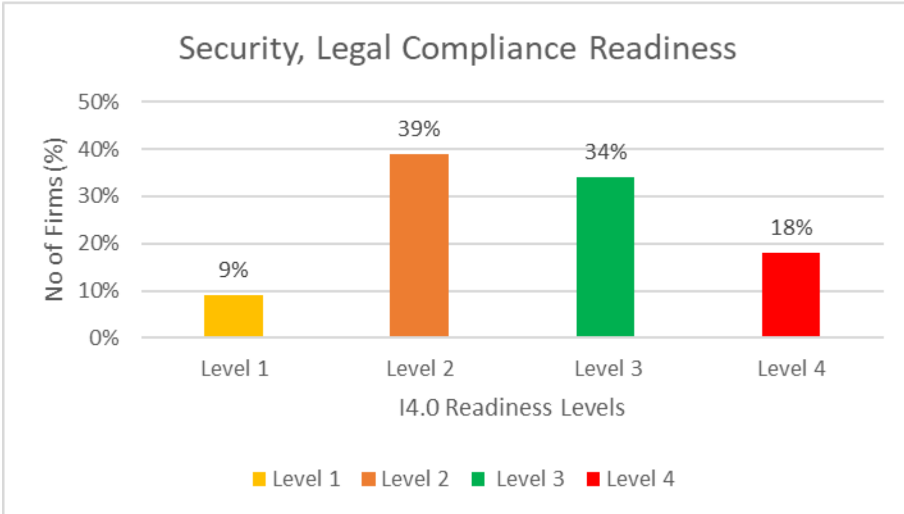

Figure 19: Security, Legal Compliance Readiness Level.

Results across all dimensions would likely have close findings because they are all connected and make sense together. For example, the smart product dimension implies equipping items with information and communications technology (ICT) elements such as communications interfaces, sensors, and RFID to gather information about their status and environment. Without these features, the workpiece cannot interact with its environment and guide itself to move through the manufacturing process autonomously. Similarly, advanced technological infrastructure is fundamental for implementing advanced technologies and their functionalities.

CHAPTER 5: STUDY 2

RESULTS AND DISCUSSION

5.1. Second Study Results

The second study aims to identify and evaluate to rank critical Industry 4.0. adoption drivers and barriers for the manufacturing firms in Pakistan. Figure 16 shows a holistic view of Industry 4.0 drivers and barriers. This chapter discusses the results of the second study. The chapter initially discusses the data's descriptive statistics and the respondents' demographic attributes.

5.1.1. Sample Descriptive:

First pairwise comparison matrices were designed for the AHP analysis of Industry 4.0 adoption drivers and barriers. Then semi-structured interviews were conducted with several identified industry experts to collect judgment-based information based on their knowledge and experience. A total of seven industry experts were interviewed: four were from the textile sector and three from other sectors (chemical and automotive). All experts were from the senior management level and had practical industry experience spanning at least 10 years. These interviews have provided thorough, context-specific insight into Industry 4.0 adoption drivers and barriers.

5.1.2. AHP Results:

Industry 4.0 adoption drivers and barriers are identified and shortlisted after a thorough literature review and experts' opinions. Five drivers and six barriers were shortlisted from a list of Industry 4.0 adoption drivers and barriers. Financial, customer requirements, increasing innovation, improving sustainability, and increasing productivity and efficiency are among the shortlisted Industry 4.0 drivers. Shortlisted Industry 4.0 barriers include organizational, financial, technological, lack of govt support, lack of clarity regarding economic benefits, and security risk.

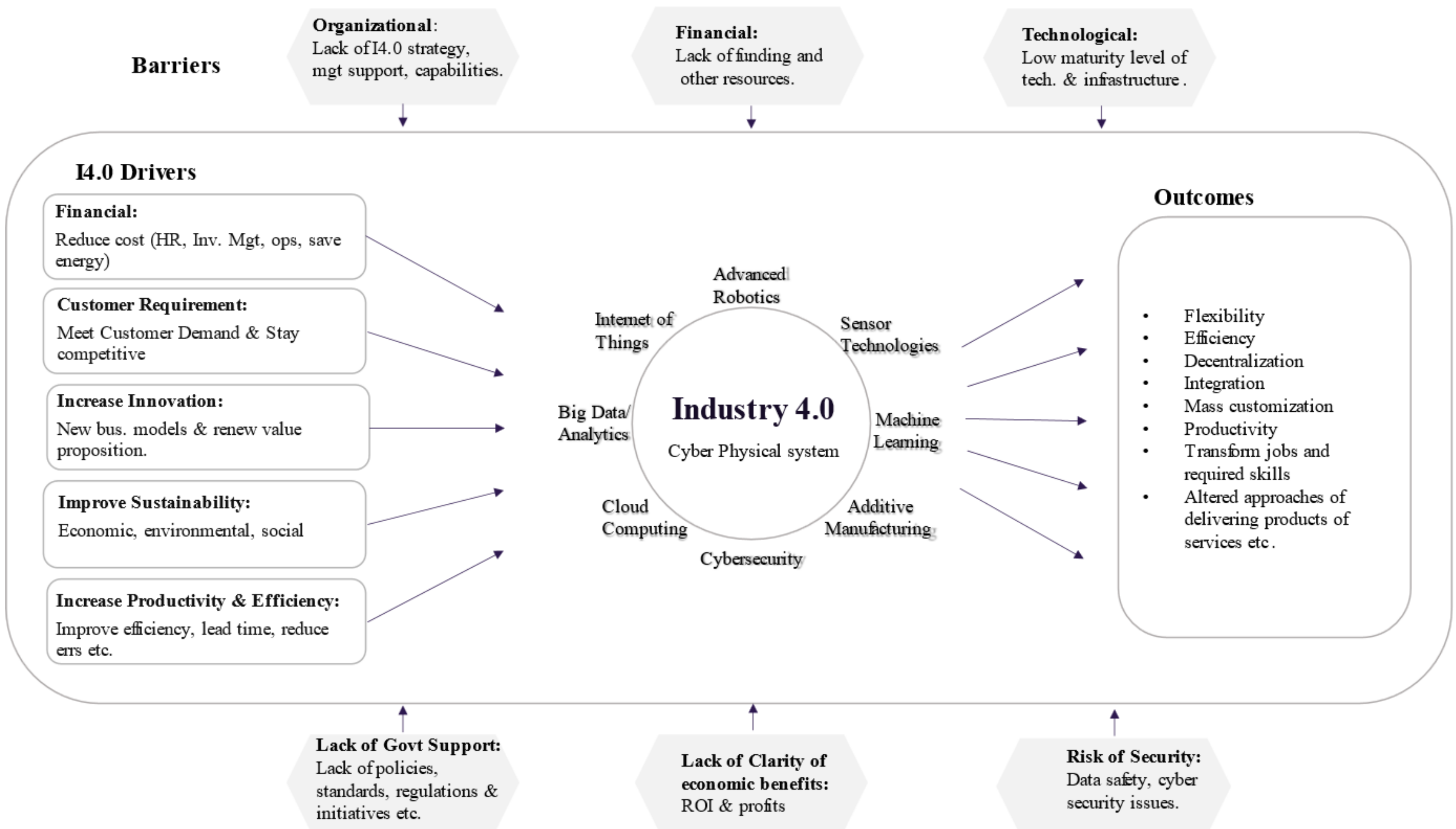

Figure 20: Schematic representation of Industry 4.0 Adoption Drivers and Barrier

After obtaining the experts' opinions, the matrices were normalized, and priority weights were calculated. Subsequently, individual matrices were consolidated in an average matrix using a simple mean. Consistency ratios (CR) were calculated to verify the consistency of the results. The consistency ratios of AHP results are below 0.1, as shown in table 6, which verifies the consistency of the results.

Table 6. CR values for all interview results.

Interview No.	Drivers CR	Barriers CR
1 (Textile)	.095	.099
2 (Chemical)	.036	.097
3 (Textile)	.08	.093
4 (Automotive)	.088	.090
5 (Automotive)	.087	.099
6 (Textile)	.10	.091
7 (Textile)	.071	.089

5.1.3. AHP Results of Industry 4.0 adoption drivers

The overall findings of AHP analysis show that the financial driver, 'cost reduction' is the most important driving force for manufacturing firms in Pakistan to adopt industry 4.0 as it is ranked at the top by most of the industry experts with an average weight of 30.2 %. Consequently, customer requirement and increased productivity & efficiency are emerged the second and third critical driving forces, with an average weight of 25% and 24.7%, respectively. The findings of several studies have indicated that cost reduction, customer requirement, and increase productivity & efficiency are the most important Industry 4.0 adoption drivers (Horváth & Szabó, 2019; Masood & Sonntag, 2020; Rauch et al., 2019; Rezqianita & Ardi, 2020; Setyaningsih et al., 2020; Stentoft et al., 2021). Setyaningsih et al. (2020) study indicated that reducing costs, such as cost of energy, human resource, operations, and inventory management, are the main reasons that encourage manufacturing firms to adopt Industry 4.0. Stentoft et al. (2021) has similar findings, illustrating cost reduction as the most influencing driving factor while customer requirements are the second most influencing driver, along with improving time to market. Rezqianita and Ardi (2020) also found productivity and efficiency as critical drivers and stated that implementing advanced technologies, a firm can improve quality by reducing errors, lead time, cycle time, data transparency, downtime, etc.

AHP results also reveal that improved sustainability and increased innovation are less important drivers with an average weight of 13.5% and 6.6%, respectively.

Table 7. Priority weights and ranking of Industry 4.0 drivers.

Drivers\ Interviews	Interview 1 (%)	Interview 3 (%)	Interview 6 (%)	Interview 7 (%)	Interview 2 (%)	Interview 4 (%)	Interview 5 (%)	Average	Ranking
Financial	6.6	20.3	38.9	49.3	30.8	42.3	23.1	30.2	1
Customer Requirement	5.7	8.1	18.3	24.1	3.7	25.3	38.7	25.0	2
Increased Innovation	2.8	12.3	4.5	4	6.1	6.5	10.1	6.6	4
Improve sustainability	15.6	8.6	11.2	8.1	27	17.9	6.1	13.5	5
Increased productivity & Efficiency	18	50.8	27.2	14.4	32.3	8	22	24.7	3
							Sum	100	

AHP Results of Industry 4.0 adoption barriers

The AHP results for Industry 4.0 adoption barriers indicate that the organizational barrier is the most influencing and critical barrier for the manufacturing firms in Pakistan to adopt Industry 4.0, with an average weight of 29.7%. The organizational barrier includes barriers i.e., lack of Industry 4.0 focused strategy, lack of senior management expertise, and support, lack of employees' digital capabilities (skills, knowledge & experience), bureaucratic and inadequate organizational structure, and employee resistance, etc. The second most critical and influencing barrier is financial, having an average weight of 17.71%. There are several studies which have analyzed Industry 4.0 adoption barriers. Each study has a different context and has used different analysis techniques. These studies have reported more or less similar findings that support results of this study (Horváth & Szabó, 2019; Majumdar, Garg, & Jain, 2021; Raj et al., 2020; Rezqianita & Ardi, 2020; Setyaningsih et al., 2020; Sharma et al., 2021; Stentoft et al., 2021; Türkeş et al., 2019; Yüksel, 2020). For example, Sharma et al. (2021) has ranked organizational barriers and implementation costs with the highest rank and states that lack of digital strategy and limited resources are the most important barrier in both developed and developing countries. Stentoft et al. (2021) study indicate that Industry 4.0 barriers such as management's failure to understand Industry 4.0's strategic importance, an overemphasis on operation at the cost of development, and employees' lack of knowledge about Industry 4.0 hold firms back from investing in Industry 4.0.

Human resource and management barrier (lack of appropriate skills, knowledge, and experience, etc. and high investment (a considerable amount of resources are required to adopt Industry 4.0) are major challenges that a firm face while implementing Industry 4.0. Yüksel (2020) noted that the most significant barrier is lack of employee's technical skills and expertise, followed by a lack of financial resources. Rezqianita and Ardi (2020) and Setyaningsih et al. (2020) studies also found organizational and financial barriers as the most influencing barriers.

Nimawat and Gidwani (2021) findings suggest that high Industry 4.0 implementation cost is the most critical barrier for developing economies, and managers should think about ways to strengthen their firm's internal abilities to overcome the barriers and facilitate Industry 4.0 adoption. The AHP results ranked the lack of Govt support barrier at third and lack of clarity regarding economic benefits with a small difference at fourth with an average weight of 14.99% and 14.82% respectively. Fernando et al. (2022) study finding show that five of the nine main barriers found in the theme analysis (such as lack of clarity about Industry 4.0 policies, high-risk investments, lack of competence, lack of incentives and the risk of data security) are the critical adoption barriers in Indonesian manufacturing supply chains.

Instead, a few firms which go for digitalization, invest in, and deploy some of the Industry 4.0 technologies that are consistent with their businesses, require minimum expenditure, and have a naive technological infrastructure. This is one of the main reasons due to which firms in developing countries like Pakistan lag to be fully prepared to adopt Industry 4.0 effectively. Industry 4.0 readiness extends beyond just investing in advanced technologies such as addressing issues related to organizational strategy, human resource skills and capabilities etc.

The AHP results indicate that technology and security risk are less important barriers, ranking fifth and sixth with an average weight of 12.83% and 9.81%, respectively. All barriers are important and need to be addressed effectively to facilitate Industry 4.0 adoption. However, analysis of pairwise comparisons of shortlisted barriers shows that organizational, financial, and Govt support barriers are comparatively more important than technology and security risk barriers. The reason behind this is, failure rate of Industry 4.0 adoption is very high because firms give more priority to technological and security risk barrier and ignore organizational and other important ones. Investing in advanced technologies and technological infrastructure cannot help without overcoming the organizational barrier. It is difficult for the firms to realize potential benefits of advanced technologies without Industry 4.0 supportive strategy, structure, employee’s capabilities, and skills etc. Similarly, most of the Industry 4.0 technologies are expensive and require a huge initial investment and other resources. The cost of acquiring and implementing advanced technologies is a critical barrier for the manufacturing firms in Pakistan, then technology and security risk barrier. Pakistan is a developing country and lags in technological research and development. The firms have to import the majority of the Industry 4.0 technologies from other countries. Without Govt support, it is difficult for firms to import new technologies.

Table 8 shows the priority weights and ranking of individual barrier factors obtained within each category.

Table 8. Priority weights and ranking of Industry 4.0 barriers.

Barriers\ Interviews	Interview 1 (%)	Interview 3 (%)	Interview 6 (%)	Interview 7(%)	Interview 2 (%)	Interview 4 (%)	Interview 5 (%)	Average	Rank ing
Organizational	50.5	33.9	43.7	11.8	14.2	9.1	45.2	29.77	1
Financial	18.2	16.4	9.4	39.3	6.2	11.4	23.1	17.71	2
Technological	3.5	23.4	14.2	14.5	13	19	2.2	12.83	5
Lack of Govt support	18.9	8	25.9	25	3.3	18	5.8	14.99	3
Lack of clarity regarding economic benefits	6.5	14.3	3.3	6.2	35.3	23.8	14.7	14.87	4
Risk of security	2.3	4	3.5	3.2	28	18.7	9	9.81	6
							Sum	100	

AHP Results of Industry 4.0 adoption drivers for the textile sector

The AHP results of the textile sector for Industry 4.0 adoption drivers also ranked financial drivers at the top with a weight of 28.78 %. The findings are same close to the overall findings of the study of all manufacturing sectors. But increased productivity & efficiency are ranked second with 27.6% and customer requirement is ranked third with 26.88%. Here results are slightly different from the overall manufacturing sector results. Improve sustainability ranked fourth and increase innovation fifth with an average weight of 10.88% and 5.9% respectively. The table 9 below shows the priority weights and ranking of individual driving factors for the textile sector obtained within each category.

Table 9. Priority weights and ranking of Industry 4.0 drivers in the textile sector.

Drivers	Interview 1 (%)	Interview 3 (%)	Interview 6 (%)	Interview 7 (%)	Average	Ranking
Financial	6.6	20.3	38.9	49.3	28.78	1
Customer Requirement	57	8.1	18.3	24.1	26.88	3
Increase Innovation	2.8	12.3	4.5	4	5.90	5
Improve sustainability	15.6	8.6	11.2	8.1	10.88	4
Increase productivity & Efficiency	18	50.8	27.2	14.4	27.60	2
				Sum	100	

AHP Results of Industry 4.0 adoption barriers for the textile sector:

Industry 4.0 barriers priority of the textile sector is that overall industry experts ranked organizational barriers at the top with a weight of 34.9%. Financial barrier priority is ranked second with 20.8% and lack of Govt support priority is ranked third with 19.4%. The AHP results of Industry 4.0 adoption barriers for the textile sector are similar to the overall results of the manufacturing sector of the study.

Majumdar et al. (2021) study has identified and evaluated the Industry 4.0 barriers in context of Indian textile sector and found that lack of knowledge, lack of skilled workforce, lack of top management commitmen, lack of govt policies & support, and inadequate research & development are the driving barriers along with high implementation cost, the fear of failure, and issues with compatibility and integration. Norman (2020) study found that the top five barriers impeding the Indonesian textile sector are as follows: (1) high investments; (2) a lack of training and digital culture; (3) a lack of digital infrastructure; (4) a lack of government support and regulations; and (5) ineffective change management.

Table 10*:* Priority weights and ranking of Industry 4.0 barriers in the textile sector.

Barriers	Interview 1 (%)	Interview 3 (%)	Interview 6 (%)	Interview 7 (%)	Average	Ranking
Organizational	50.5	33.9	43.7	11.8	34.97	1
Financial	18.2	16.4	9.4	39.3	20.82	2
Technological	3.5	23.4	14.2	14.5	13.9	4
Lack of Govt support	18.9	8	25.9	25	19.45	3
Lack of clarity regarding economic benefits	6.5	14.3	3.3	6.2	7.57	5
Risk of security	2.3	4	3.5	3.2	3.25	6
				Sum	100	

Chapter 6

Discussion, Implications, Limitations, Future recommendations, and conclusion

6.1. Discussion

The adoption of Industry 4.0 can significantly revolutionize how businesses operate and allow them to access new sources of value. To realize this transformation, manufacturing firms and their managers must have a comprehensive understanding of the Industry 4.0 and determine the degree to which their firm is ready to adopt it. And how they can overcome challenges to successfully implement advanced technologies to add value. By mapping the current, as-is situation, the management can gain valuable insight to get through the journey of Industry 4.0 implementation. The application of various technologies differs from one firm to another and from country to country. It is widely known that adopting new technologies is more challenging in developing nations, owing to scarce resources, education level, culture, political instability, etc. Therefore, enterprises in developing countries lag behind those in developed nations in terms of technology adoption (Shi et al., 2020). This study has two main aims: (1) to assess the readiness of manufacturing firms for the adoption of Industry 4.0 in Pakistan and (2) to evaluate and rank Industry 4.0 adoption drivers and barriers in Pakistan.

The survey findings of the first study underline that manufacturing firms in Pakistan have limited knowledge of Industry 4.0 and are not prepared to adopt it. The survey response rate was very low, and out of a total of 130 responses, the sample size was reduced to 82 due to the participants' lack of Industry 4.0 knowledge, understanding, and engagement. Results of this study show that 41% of the surveyed firms do not have an industry 4.0-focused strategy. 44% of firms have not invested in Industry 4.0, and 12% of firms have invested less than 1 million PKR. 25% of firms are not using new technologies at all. Mobile devices, sensor technology, and RFID are the most employed technologies, as results show their usage at 39.5 percent, 34%, and 23%, respectively, in manufacturing firms. 60% of the surveyed firms used only ERP, and 21% did not use any information system. The survey sample includes 58% large firms and 42% SMEs. Larger organizations appear to be more ready to adopt the industry than SMEs.

The 2015 "Global Innovation Index (GII)" provides a rich dataset for identifying and analyzing global innovation trends. The survey includes 141 countries worldwide and employs 79 indicators (i.e., innovation linkages, creative goods and services, and individual skills) along various themes. GII (2015) ranks Pakistan 131 out of 141 countries on the list of the world's most innovative nations (Raza, Minai, Zain, Tariq, & Khuwaja, 2018). Likewise, the 2015–2016 "Global Competitiveness Report" evaluates the competitive landscape of 140 countries. And Pakistan was ranked 126th out of 140 countries in innovation, emphasis on business sophistication, technological readiness, and infrastructure (World Economic Forum, 2016). The Pakistani manufacturing sector continues to encounter several risks and challenges, such as inadequate financial resources, poor infrastructure, obsolete production facilities, a lack of entrepreneurial abilities, an incompetent workforce, difficulties getting loans from financial institutions, a complicated taxation system, etc.

Tripathi and Gupta (2021) argued that the low worldwide average readiness score indicates that most of the world has not yet comprehended the Industry 4.0 concept at the country level. Based on observations of their digital infrastructure, many of these countries lack the characteristics of the third industrial revolution. According to Tortora et al. (2021) study, most firms are not yet aware of the prospects that Industry 4.0 technologies may provide; thus, they must develop a thorough understanding of the various components of Industry 4.0 and acquire the necessary confidence, knowledge, and skills. Yüksel (2020) study findings underline that although many firms agree that Industry 4.0 would provide several benefits, a considerably smaller percentage of them are developing strategies for and investing in Industry 4.0 technologies. But in developing countries, issues with management, labor skills, and financial resources prevent SMEs from investing in Industry 4.0 technologies.

There are many Industry 4.0 adoption drivers and barriers discussed in the literature. Five drivers were shortlisted and three of them; financial, customer requirement, and increased productivity and efficiency emerge as the most influencing forces for manufacturing firms to adopt Industry 4.0 in the context of Pakistan, while two other improving sustainability and increasing innovation appears less critical compared to the other drivers. Similarly, three of the six shortlisted barriers organizational, financial, and a lack of government support, emerge as the most vital, while the other three—lack of clarity about economic benefits, technological risks, and security risks—emerge as less important when compared to other barriers.

Prioritizing essential drivers and barriers enables decision-makers to focus on opportunities of considerable significance and overcome critical barriers for effective transformation. These findings are important for manufacturing firms to consider when they plan transformation and make an implementation roadmap based on specific organizations' criteria and objectives. Perceived drivers encourage decision-makers and make firms more Industry 4.0-ready, which plays a vital role in the actual adoption of Industry 4.0 technologies.

It is difficult for large organizations to make structural changes due to their size and bureaucratic culture. They face employees' resistance, and the lack of employees' digital knowledge and capabilities impedes digital transformation (Ślusarczyk, 2018). Lack of Industry 4.0 knowledge is a key challenge when dealing with advanced technologies. Decision-makers lack a thorough understanding of this innovation surge's technologies, drivers, and barriers (Calabrese, Levialdi Ghiron, & Tiburzi, 2021).Therefore, manufacturing firms and managers must have in-depth knowledge of the underlying concept and ought to design adoption roadmaps and make strategic plans to guide actions to facilitate Industry 4.0 transformation. Especially top management should know about the benefits and strategic steps of Industry 4.0 adoption. Leaders need to carefully assess the human resources competencies and analyze the digital capabilities of the employees. Therefore, it can identify the lack of skill sets and provide up-skilling and re-skilling programs for its employees.

The other critical barrier to the adoption of Industry 4.0 is financial, as the employment of new technologies requires large investments and other resources. Usually, firms value operational excellence that is economically viable. The decision-makers raised concerns regarding a lack of adequate funds to adopt Industry 4.0 due to its high initial investment costs (Yadav, Luthra, Jakhar, Mangla, & Rai, 2020). Companies in developed economies and large companies overall have financial muscles, and organizational barriers are the most critical ones for them. But companies in developing economies, especially SMEs compared to large firms, work with limited resources and seem more concerned with financial barriers. According to Calabrese et al. (2021), SME managers are likely to give more importance to high cost and the government framework as critical Industry 4.0 barriers than large firms managers do.

The third most critical barrier that emerges from this study is the lack of government support. Different policies exist in different countries to facilitate the transition to adopt Industry 4.0. Most developed economies have articulated national strategies and initiatives for Industry 4.0 adoption. Developing countries, on the other hand, have taken individual initiatives on a corporate level for Industry 4.0 adoption rather than formulating coordinated policies at the national level (Raj et al., 2020). However, in Pakistan scenario, there are lack of government policies regarding Industry 4.0 adoption, initiatives, subsidies, advanced ICT infrastructure, standards, regulations, forms of certification, etc.

6.2. Conclusion

Knowing readiness of a firm for Industry 4.0 is an essential step to embrace the successful transformation. The first study has analyzed readiness of manufacturing firms for adoption of Industry 4.0 in Pakistan. And second study has evaluated Industry 4.0 adoption drivers and barriers and ranked them by using priority weights that are calculated based on industry expert's opinions. Findings shows that manufacturing firms in Pakistan are not ready to adopt Industry 4.0. A noticeable number of firms do not have Industry 4.0 focused strategy and have not invested much in advanced technologies. There is lack of Industry 4.0 understanding and firms are not aware of potential benefits of advanced technologies. Employees lack capabilities and skills essential to work with advanced technologies. Lack of Industry 4.0 understanding, lack of employee's capabilities and skills, insufficient funds, lack of Govt support are prominent adoption barriers which are holding back Pakistan manufacturing firms to adopt Industry 4.0. In contrast, drivers such as cost reduction, customer's requirement, and increase productivity & efficiency are ranked as first, second, and third respectively. The perceived drivers make firms more ready to adopt Industry 4.0.

6.3. Implications, Future Recommendations, and Limitations

In the future, Industry 4.0 adoption may improve as larger organizations find more practical applications and government support. There is a need of improvements in technological infrastructure and legal frameworks to support Industry 4.0 adoption (Yüksel, 2020). To facilitate Industry 4.0 adoption, policymakers should take advantage of Industry 4.0 adoption initiatives and provide grants and subsidies to manufacturing firms. Such initiatives will increase enterprises' enthusiasm for adopting Industry 4.0. Industry 4.0 is still quite novel for developing countries like Pakistan and requires a precise definition for comprehensive understanding and practice. It is suggested that policymakers should conduct awareness campaigns to create awareness and educate employees who can play an active role in implementation of such initiatives.

Decision-makers must focus on the drivers along with barriers for effective Industry 4.0 adoption. They should look at the potential benefits instead of only focusing on the barriers. Indeed, raising awareness of the business cases for employing advanced technologies appears to be the foremost important factor in preparing firms for Industry 4.0 and encouraging their investment in Industry 4.0 technologies. Businesses still doubt the adoption of advanced technologies due to the large investment requirements, lack of clear potential benefits, and ambiguity in implementation details. When the business situation is evident, working with drivers will help reduce the obstacles. Academic institutions can help manufacturers adopt Industry 4.0 by pursuing technology development through research and adapting the academic curriculum to satisfy the specific demands of Industry 4.0 talent. Future research on assessing manufacturing firms' readiness for Industry 4.0 will yield more results. Studies could be done to assess the readiness of specific manufacturing sectors and compare them with each other for better understanding. The first study concluded with 82 firm responses from all manufacturing sectors. The second study, like the first, is based on seven expert interviews. Future research can use a larger sample size to generalize findings. Research can also be carried out on different sectors to compare results and on specific manufacturing sectors to get more in-depth insight. Researchers can also propose road maps and strategies for successful Industry 4.0 adoption and to overcome barriers.

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Annexure

Annexure A-Survey Questionnaire

SECTION A: General Information

Please respond to all questions.
Please tick (✓) choice/choices in each question as follows:

Please note the time on your watch before starting this questionnaire: _____ hours ____ minutes.

1. **What is your mood now?**
   a) Happy
   b) Neutral
   c) Sad

2. **What is your current/last designation?**
   (a) Senior Manager
   (b) General Manager
   (c) Director
   (d) C-level executive (CEO, COO, CTO, CIO, etc.)
   (e) Other, please specify……

3. **How will you classify your manufacturing firm?**
   (a) Automotive and automotive accessories
   (b) Chemical and Allied Industry
   (c) Electronic and Electrical Equipment Industry
   (d) Food and Beverages Industry
   (e) Leather Industry
   (f) Mechanical Machinery
   (g) Metal Products
   (h) Rubber and Miscellaneous Plastic Industry
   (i) Surgical Instrument sector
   (j) Textile Industry
   (k) If any other, please specify…………

4. **What is the name of your company/firm?**

5. **Where your company/firm is located (city/area)?**

6. How will you classify your sector?

(a) Private Limited
(b) Public Limited
(c) Multinational Corporation
(d) State Owned Enterprises
(e) If any other, please specify…………

7. Please estimate the size of your company's domestic workforce.

(a) Under 50 employees
(b) 51 to 99 employees
(c) 100 to 199 employees
(d) 200 to 299 employees
(e) 300 to 399 employees
(f) 400 to 499 employees
(g) 500 above employees

SECTION B

Please select the appropriate option(s) for multiple-choice questions.

8. What is the implementation status of your Industry 4.0 strategy?

(a) No strategy exists (Planning to Invest in Industry 4.0 but no strategy devised yet)
(b) Pilot initiatives launched.
(c) Strategy in development
(d) Strategy formulated.
(e) Strategy in implementation.
(f) Strategy implemented.
(g) Not planning to invest in Industry 4.0.

1.

9. In which business area has your firm invested for the implementation of Industry 4.0.

(a) Research and development
(b) Production/manufacturing
(c) Procurement & Purchasing
(d) Logistics
(e) Marketing & sales
(f) Services
(g) IT
(h) If any other, please specify……
(i) Not invested in any business area related Industry 4.0. (if selected this please skip Q.No.7)

10. **How much has your firm invested in the implementation of Industry 4.0 in past five years?**
    (a) No Investment
    (b) Under 1 million PKR
    (c) 1 million to under 5 million PKR
    (d) 5 million to under 10 million PKR
    (e) 10 million to under 20 million PKR
    (f) 20 million to under 50 million PKR
    (g) 50 million PKR and above

11. **Which of the following technology/technologies are being used in your firm? Please select one or more options.**
    (a) Sensor technology
    (b) Mobile end devices
    (c) Radio frequency Identification Device (RFID)
    (d) Real-time location systems
    (e) Big data to store and evaluate real-time data.
    (f) Cloud Computing technologies
    (g) Machine-to-machine (M2M) communication
    (h) Internet of Things (IoT)
    (i) Cyber Physical systems (CPS)
    (j) Autonomous Robots
    (k) Augmented Reality
    (l) Artificial Intelligence
    (m) If any other, please specify…………
    (n) Not applicable (not using any such technology)

12. **Which of the following information system(s) are being used in your firm? Please select one or more options.**
    (a) **MES** – manufacturing execution system
    (b) **ERP** – enterprise resource planning
    (c) **PLM** – product lifecycle management
    (d) **PDM** – product data management
    (e) **PPS** – production planning system
    (f) **PDA** – production data acquisition
    (g) **MDC** – machine data collection
    (h) **CAD** – computer-aided design
    (i) **SCM**–supply chain management
    (j) If any other, please specify…………
    (k) **Not applicable** (not using any such information system)

13. **The products are equipped with which of the following add-on functionalities based on information and communication technology.** Please select one or more option(s).

(a) Product memory
(b) Self-reporting
(c) Integration
(d) Localization
(e) Monitoring
(f) Object Information
(g) Automatic identification
(h) If any other please specify……………….
(j) Not applicable (No such product add-on functionalities)

14. Which types of tools used in the company for collaboration.

(a) Online meetings & Team messaging (Zoom, MS teams, Skype, Slack, Emails, Drive, Google Hangouts, Fuze etc.)
(b) Project & task management (Trello, Airtable, Asana, Basecamp, Wrike etc.)
(c) File storage & Sharing (Google Drive, Dropbox Business, MS Share points, Confluence etc.)
(d) Collaborative content creation (Trello, Flip board, My Blog U etc.)
(e) If any other, please specify……
(f) Not applicable (not use any collaborative tool)

Note:

Statements in this section are rated on a 1-4 scale. A value of 1 indicates a very high degree of disagreement with the statement (strongly disagree), 2 represents disagreement with the statement (disagree), 3 represents agreement with the statement (agree), and 4 indicates a high degree of agreement (strongly agree) with the statement. Please select one option that most closely expresses your views against the statements.

15. Executive and senior management have expertise, involvement, and support in Industry 4.0 initiatives.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

16. The employees have digital capabilities (skills, knowledge & understanding) and experience.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

17. The company has invested in targeted digital education and training at all levels (operational level, middle management, top management level etc.) of the organization.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

18. The organization model encourages cross-functional (between departments) and cross-enterprises (external partners i.e., suppliers, customers etc.,) collaboration.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

19. **Collaboration with partners, suppliers, and clients for the development of products and services is intensive. (**Collaborative development of products together with partners.)
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

20. **Firm KPI's are focused on Industry 4.0**.
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

21. **IT architecture of the firm address the overall requirements from digitization and Industry 4.0.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

22. **The firm has advanced digitization level of production equipment (sensors, IoT connection; digital monitoring, control, optimization & automation).**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

23. **Machines and systems can be controlled completely through automation and do not require human intervention.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

24. **Machines are fully integrated within the firm.** (Machine integration is machine-to-machine communication while integrated operating systems combine two or more systems i.e., CRM, ERP, SCM system etc.)
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

25. **Systems are fully integrated within the firm. (**Integrated operating systems combine two or more systems i.e., CRM, ERP, SCM system, etc.)
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

26. **There is full IT integration with customers, suppliers, and fulfillment partners.** (Interfaces for all relevant IT systems allow seamless and secure data exchange e.g., complete order tracking for customers, inventory insight for supplier etc.)
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

27. **Autonomously guided workpieces and self-optimizing processes are widely used in the factory.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

28. **Firm has production processes that respond autonomously/automatically in real-time to changes in production conditions.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

29. **Adaptability of the firm's equipment infrastructure is high in machine-to-machine (M2M) communication, integration, and collaboration with other machines/systems.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

30. **An average product in the portfolio is completely digitalized (e.g., RFID for identification, sensors, IoT connection, etc.).**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

31. **Customers can largely customize the product(s) they order rather than standardize mass production.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

32. **The data gathered in the production, processes, and in usage phase enable new services. The firms offer such data-driven services with full customer integration.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

33. **The firm has the capability to create value from data (e.g., analytics team, data scientist, etc.).**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

34. **During production, machine and process data is collected and used across the entire process.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

35. **More than 50% of the product data collected in usage phase is analyzed and used.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

36. Extensive customer data at all touch points (customer contact with the brand) is collected and analyzed to monitor, review, and optimize products, sales, and customer experience.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

37. Data-driven services account for a significant share of revenue (>10%).

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

38. Inventory is managed using real-time data management which is updated by smart devices.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

39. Supply chain is fully integrated (real-time information sharing, coordination & alignment) from customer order over suppliers, production, and logistics to service.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

40. Site location, capacity, inventory, and operations are visible in real-time throughout supply chain and used for monitoring and optimization.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

41. There is immediate response to changes in market, environment, and individual customer requirements.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

42. Multiple integrated digital and non-digital sales channels (e.g., store, sales force, web shop, sales platforms etc.) are used to sell products to customers.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

43. Multiple channels (website, blogs, forums, social media platforms, etc.) are integrated into customer interactions for communicating news, receiving feedback, managing claims etc.

1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

44. **Sales force is supported by digital devices and can access to all relevant processes and systems at any time.** (real-time access to customer and product data, possibility to configure personalized products and dynamically create orders etc.)
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

45. **The firm has a sophisticated digital compliance policy.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

46. **Data protection policies and procedures are well defined and implemented.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

47. **Production is completely integrated into the security concept and respective mechanisms are implemented to protect production from cyber threats.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

48. **Risk associated with the digitization of products and production itself are completely addressed by risk management.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

49. **Intellectual property (IP) of the digital products and services is protected properly, and do not violate external IP.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

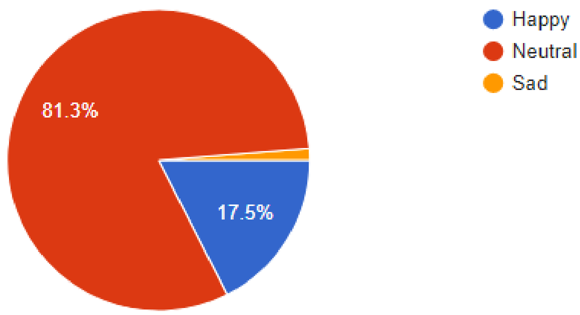
50. **We do not violate external IP (intellectual property)**
    1. Strongly Disagree 2.Disagree 3. Agree 4. Strongly Agree

51. **Special approach for digital assets, location and the set up for the digital property (licenses, patent, IP etc.) is handled in a tax optimized way.**
    1. Strongly Disagree 2. Disagree 3. Agree 4. Strongly Agree

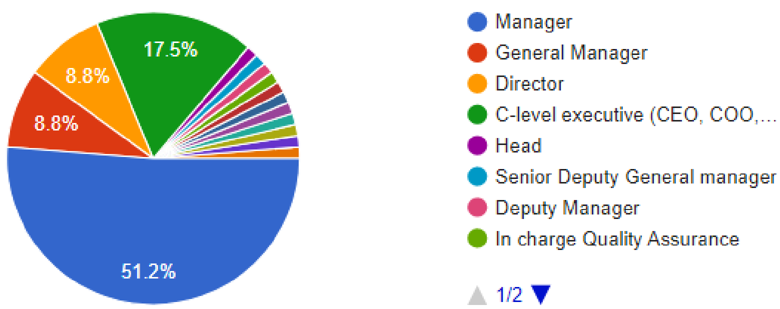
Please note down time on your watch after completion of the survey: _____ hours ____ minutes.

Annexure-B Survey Results

1. **What is your mood now?**

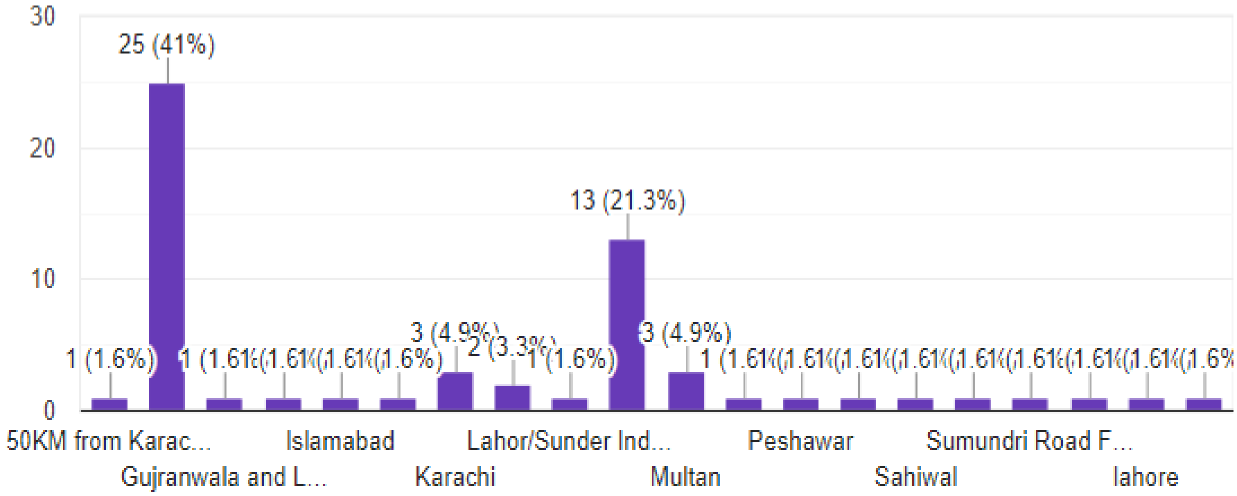


2. **What is your current/last designation?**

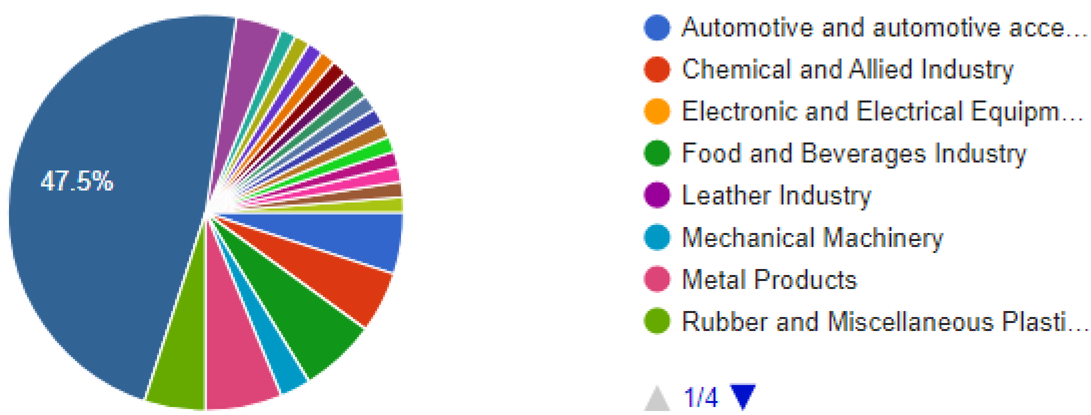


3. **What is the name of your company/firm?**

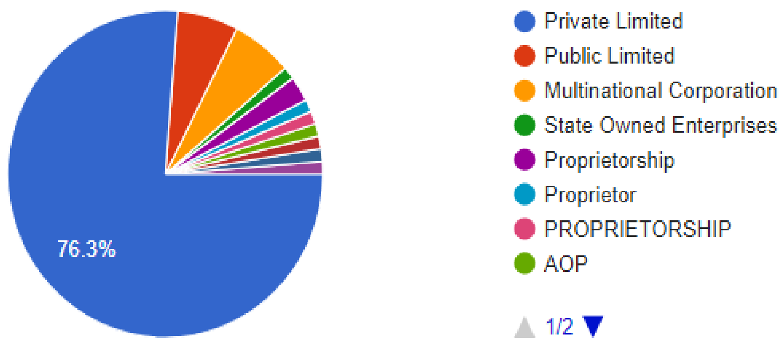
4. **Where your company/firm is located (city/area)?**



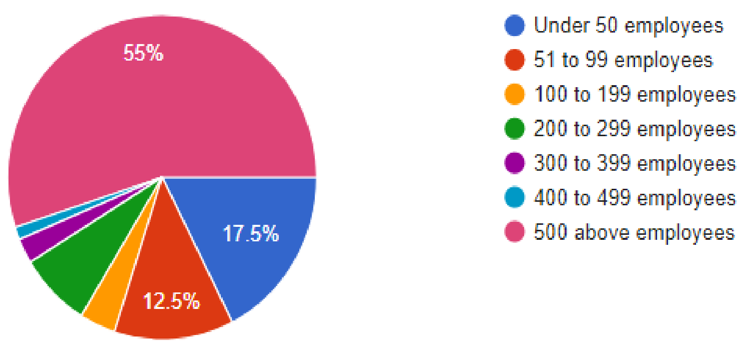
5. **How will you classify your manufacturing firm?**



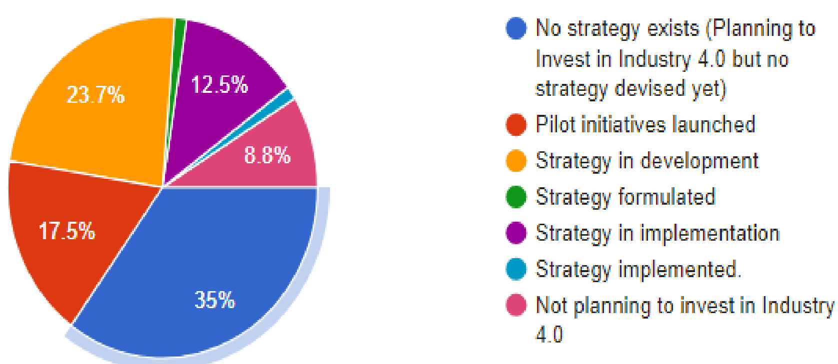
6. **How will you classify your sector?**



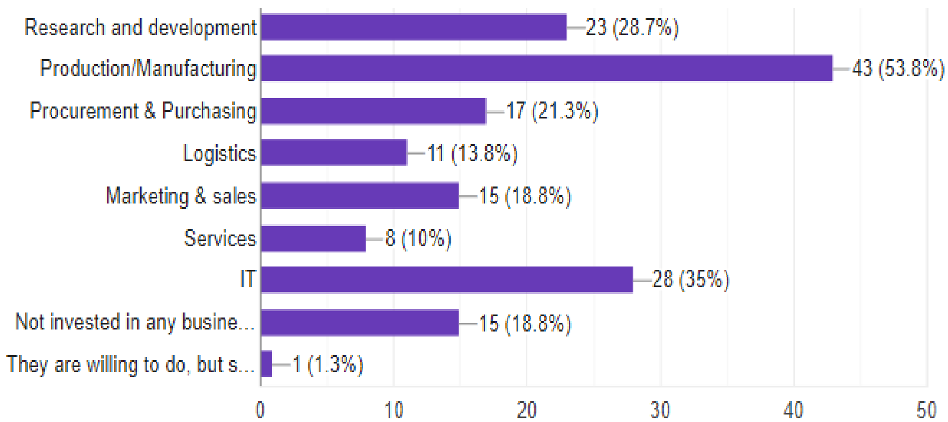
7. **Please estimate the size of your company's domestic workforce.**



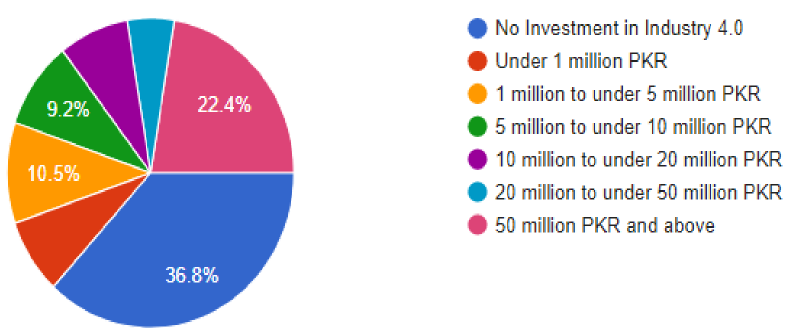
8. **What is the implementation status of your Industry 4.0 strategy?**



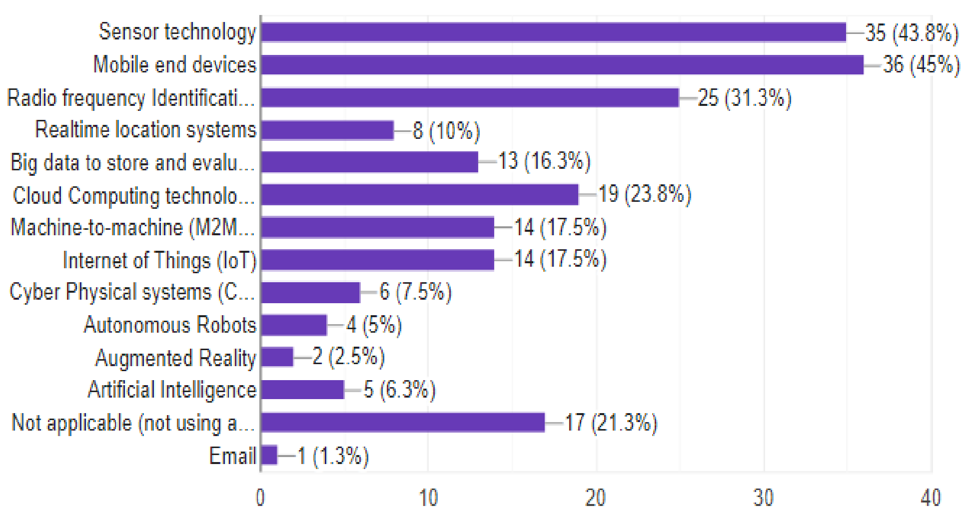
9. **In which business area has your firm invested for the implementation of Industry 4.0.**



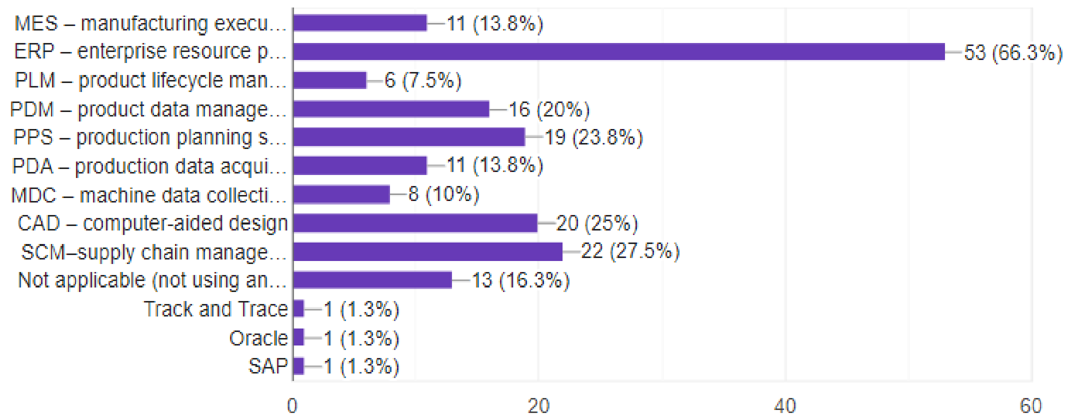
10. **How much has your firm invested in the implementation of Industry 4.0 in past five years?**



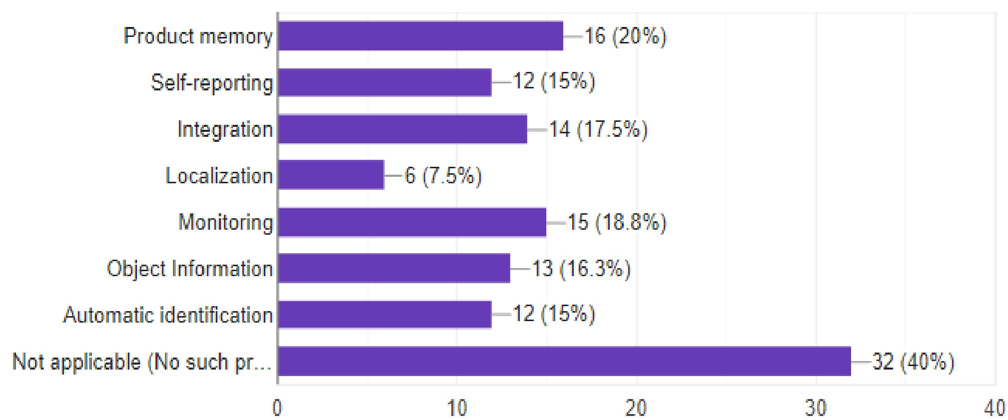
11. **Which of the following technology/technologies are being used in your firm? Please select one or more options.**



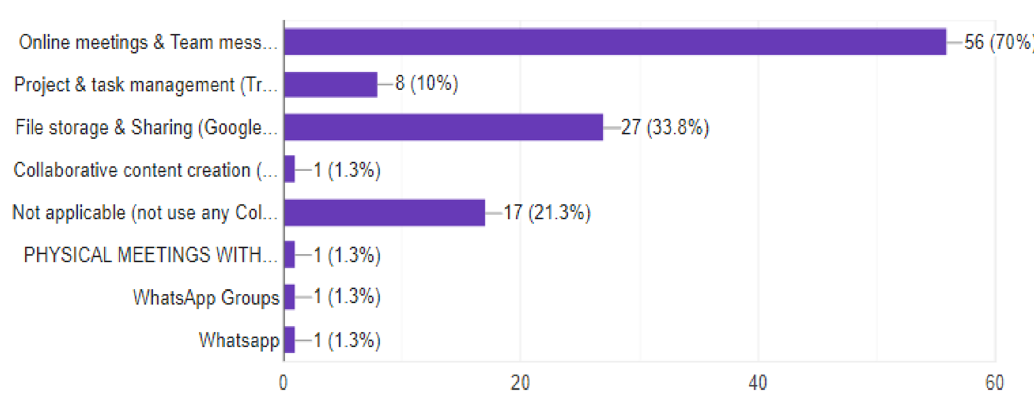
12. Which of the following information system(s) are being used in your firm? Please select one or more options.



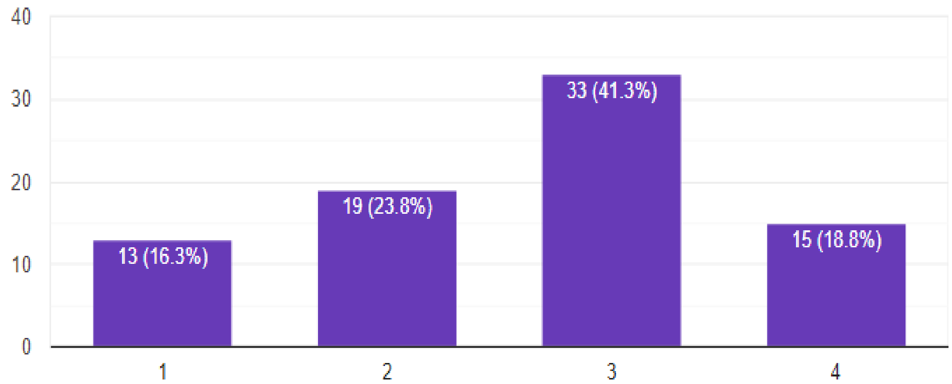
13. The products are equipped with which of the following add-on functionalities based on information and communication technology.



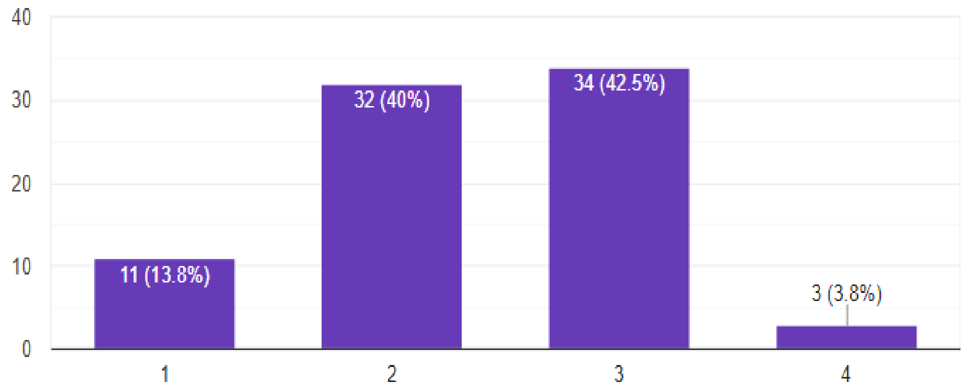
14. Which types of tools used in the company for collaboration.



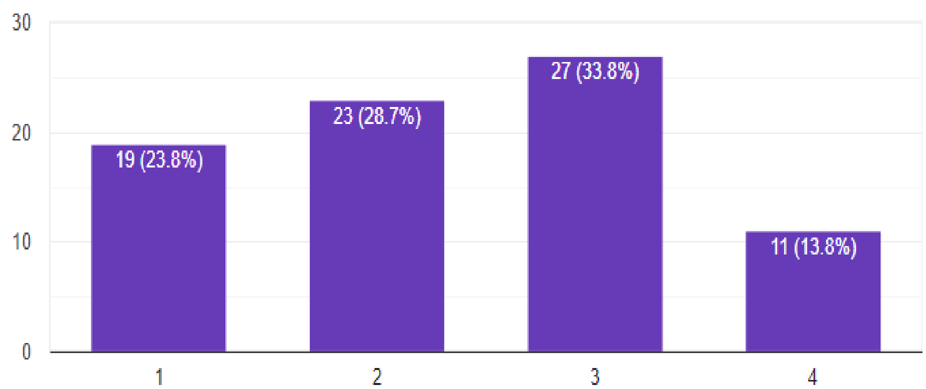
15. Executive and senior management have expertise, involvement, and support in Industry 4.0 initiatives.



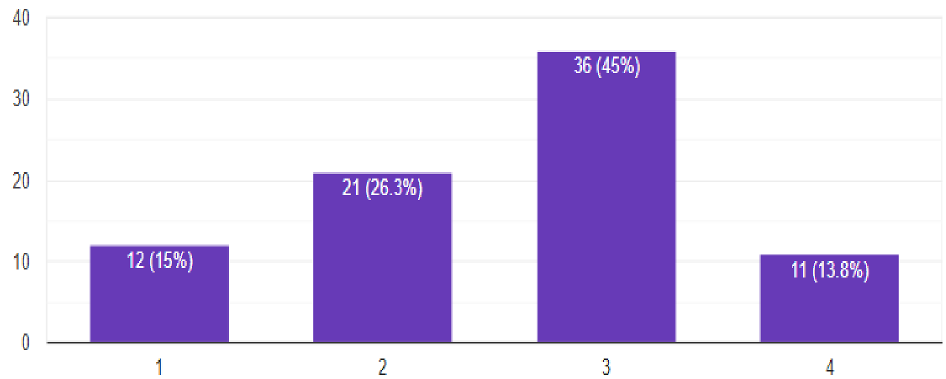
16. The employees have digital capabilities (skills, knowledge & understanding) and experience.



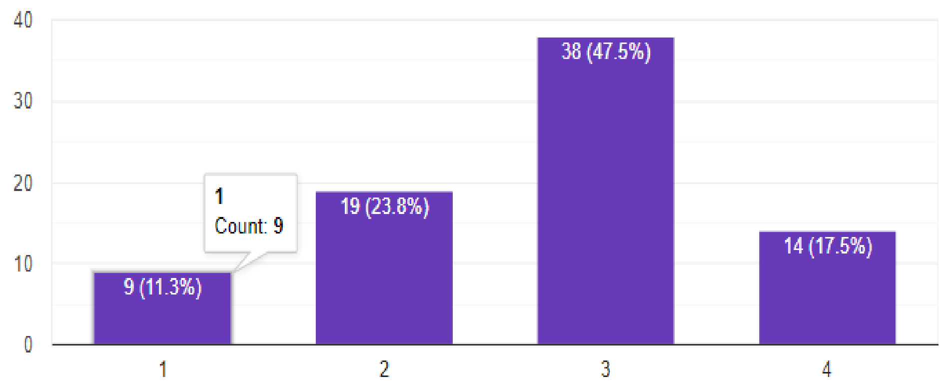
17. The company has invested in targeted digital education and training at all levels (operational level, middle management, top management level etc.) of the organization.



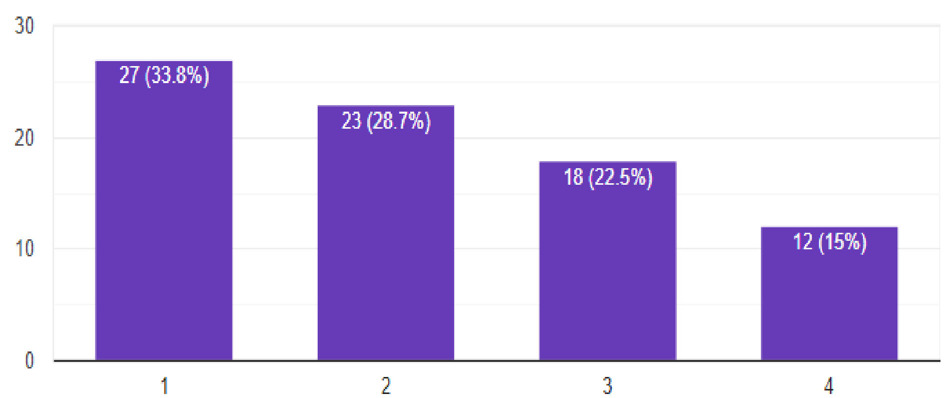
18. The organization model encourages cross-functional (between departments) and cross-enterprises (external partners i.e., suppliers, customers etc.) collaboration.



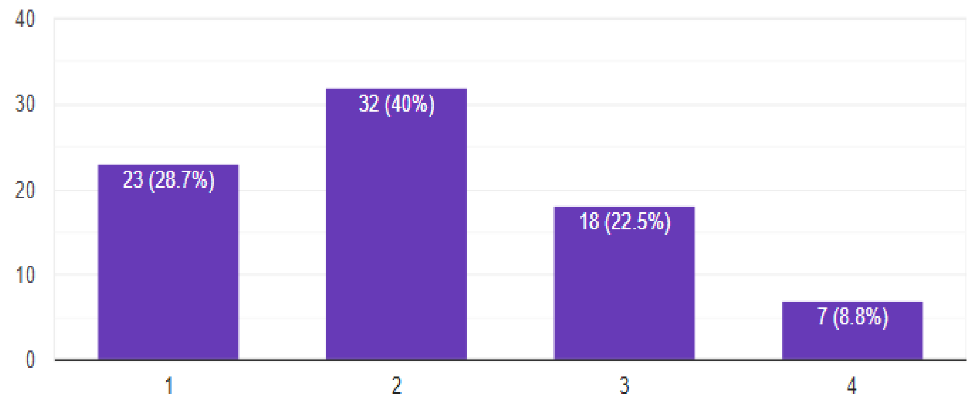
19. Collaboration with partners, suppliers, and clients for development of products and services is intensive.



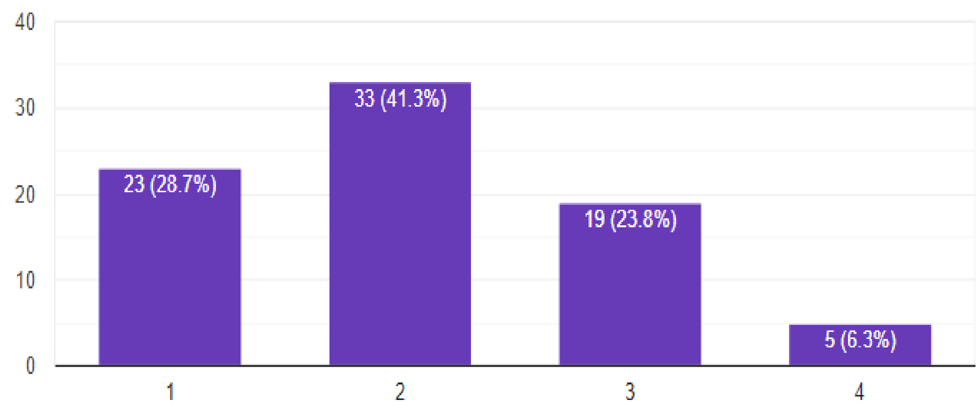
20. Firm KPI's are focused around Industry 4.0.



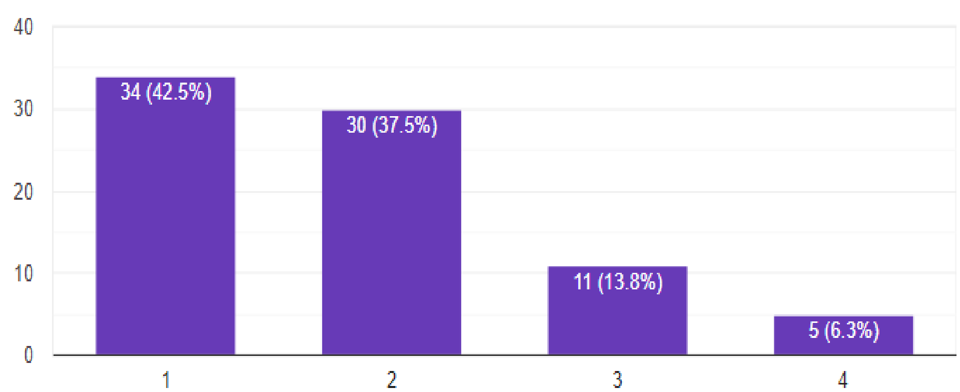
21. IT architecture of the firm address the overall requirements from digitization and Industry 4.0.



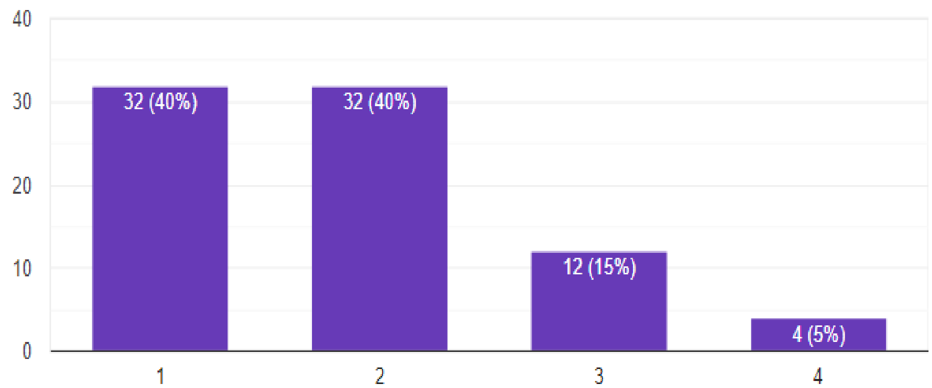
22. The firm has advanced digitization level of production equipment (sensors, IoT connection; digital monitoring, control, optimization & automation).



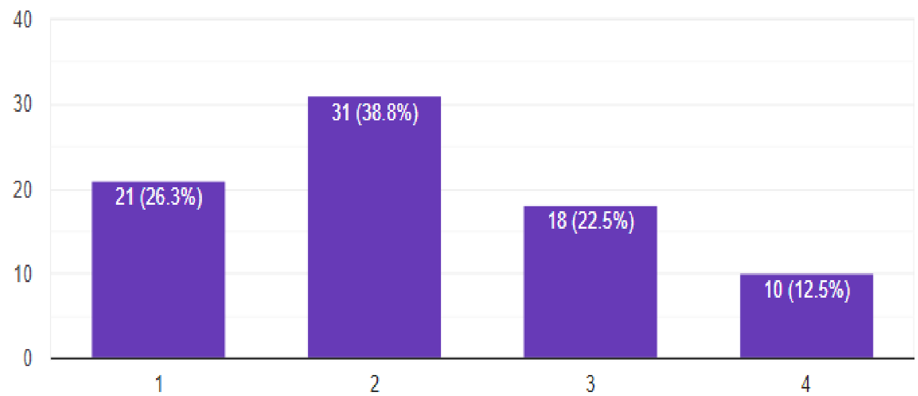
23. Machines and systems can be controlled completely through automation and do not require human intervention.



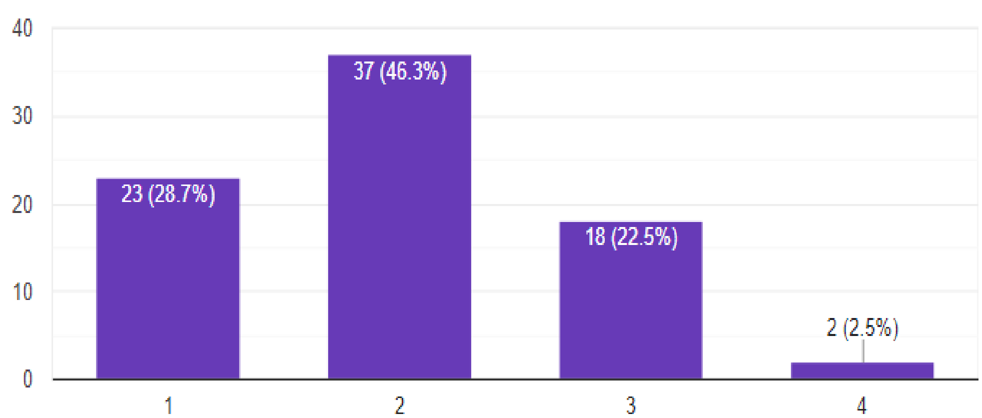
24. Machines are fully integrated within the firm.



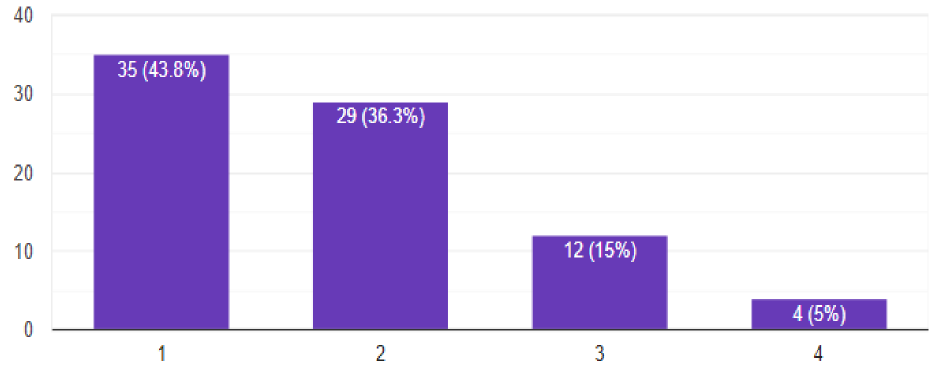
25. Systems are fully integrated within the firm.



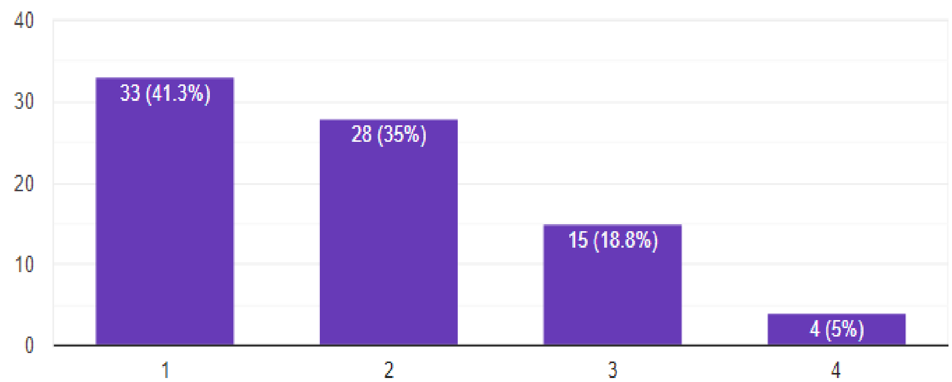
26. There is full IT integration with customers, suppliers, and fulfillment partners.



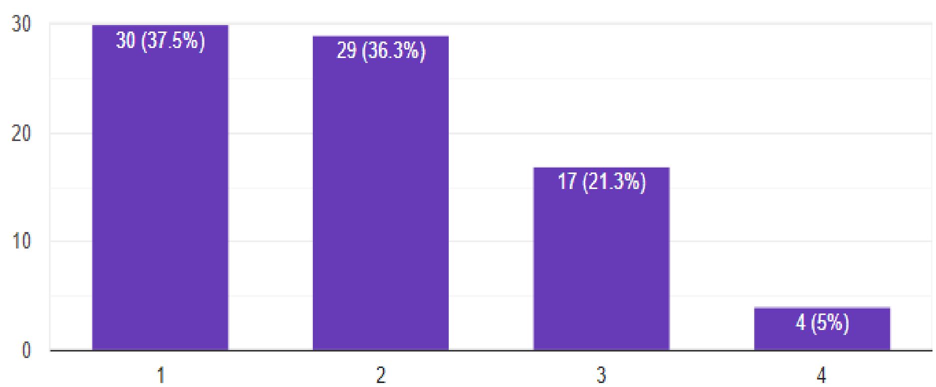
27. Autonomously guided work pieces and self-optimizing processes are widely used in the factory.



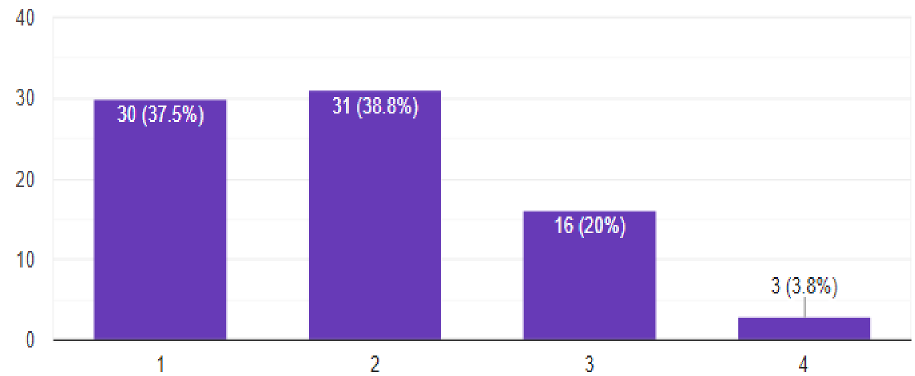
28. Firm has production processes that respond autonomously/automatically in real time to changes in production condition.



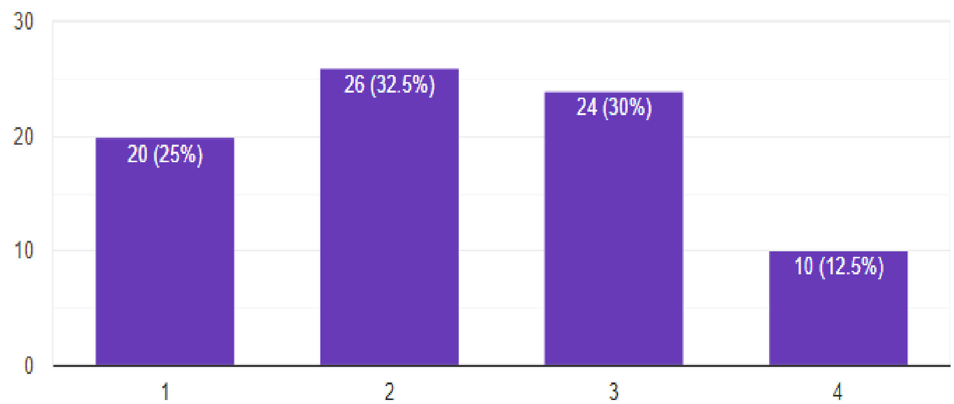
29. Adaptability of firm's equipment infrastructure is high with regards to machine-to-machine (M2M) communication, integration, and collaboration with other machines/systems.



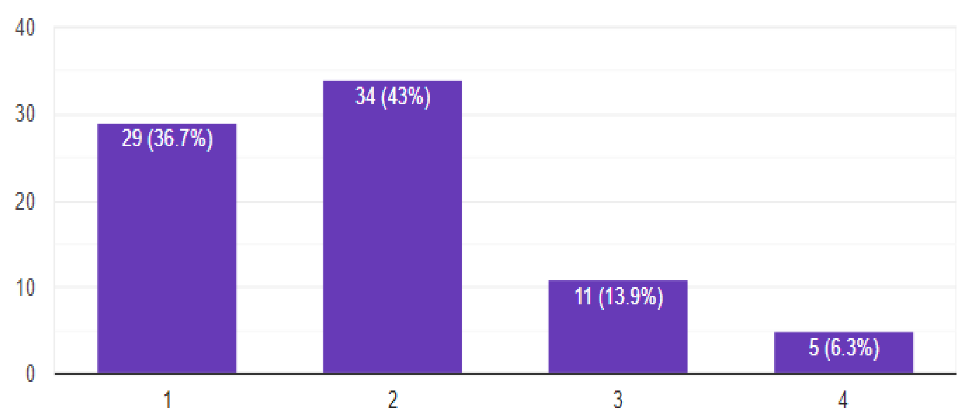
30. An average product in the portfolio is completely digitalized (e.g., RFID for identification, sensors, IoT connection, etc.).



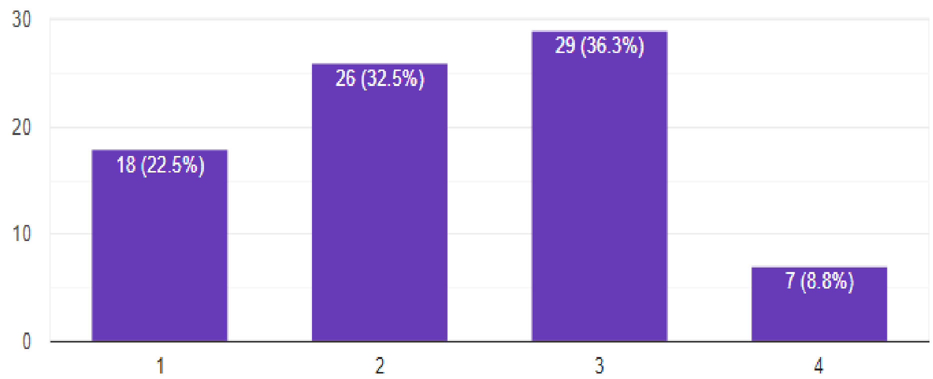
31. Customers can largely customize product(s) they order rather than standardize mass production.



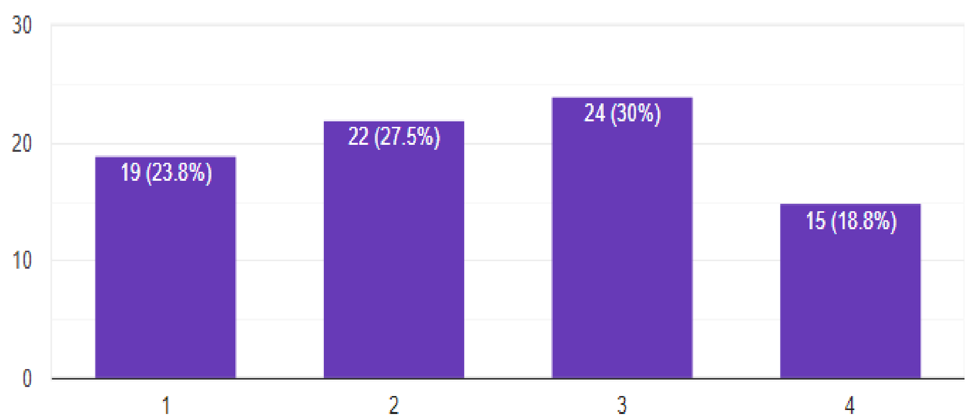
32. The data gathered in production, processes, and in usage phase enable new services. The firm offer such data-driven services with full customer integration.



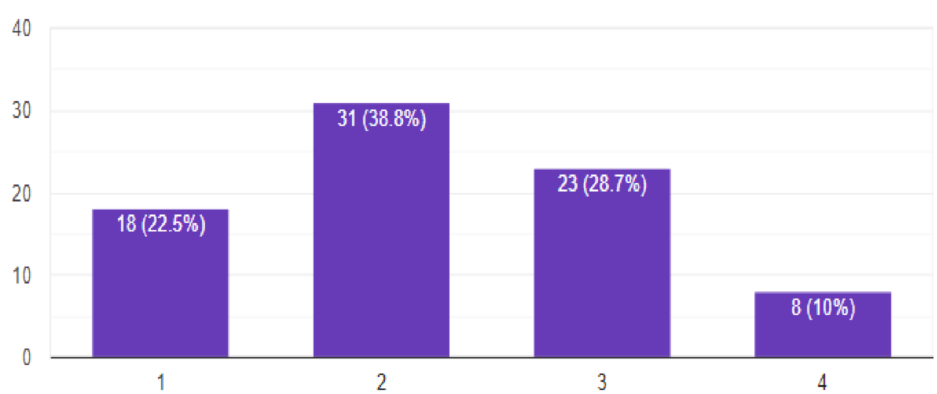
33. The firm has the capability to create value from data (e.g., analytics team, data scientist etc.).



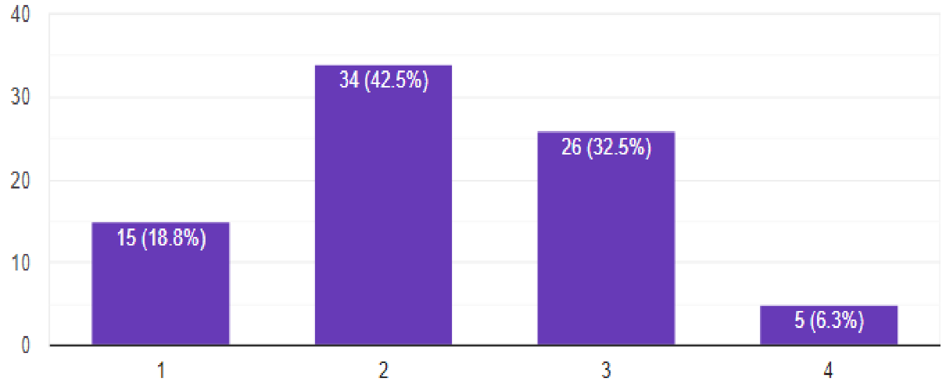
34. During production, machine and process data is collected and used across the entire process.



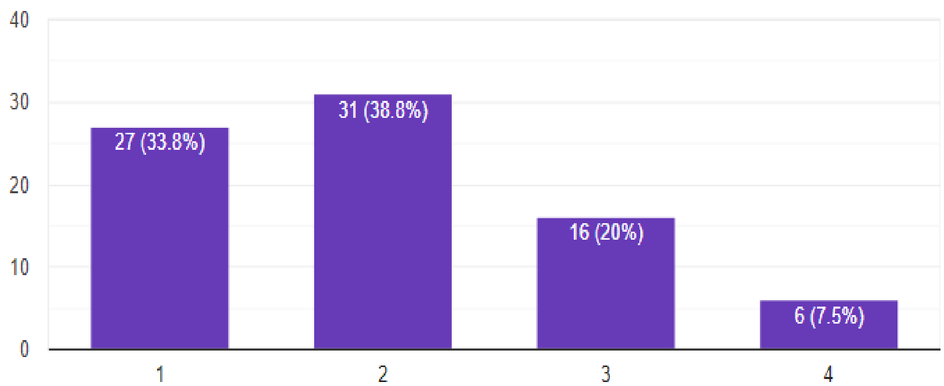
35. More than 50% of the product data collected in usage phase is analyzed and used.



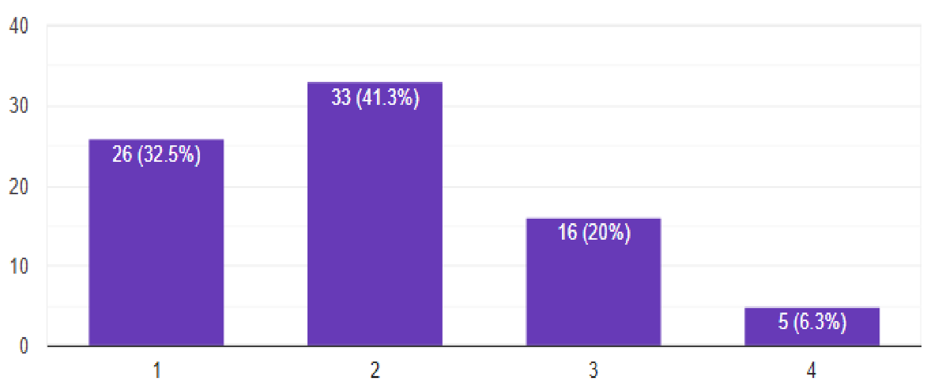
36. Extensive customer data at all touch points (customer contact with brand) is collected and analyzed to monitor, review, and optimize products, sales, and customer experience.



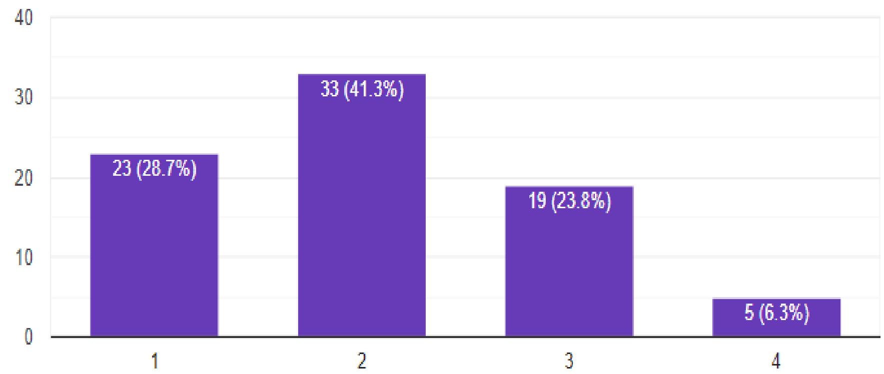
37. Data driven services are account for a significant share of revenue (>10%).



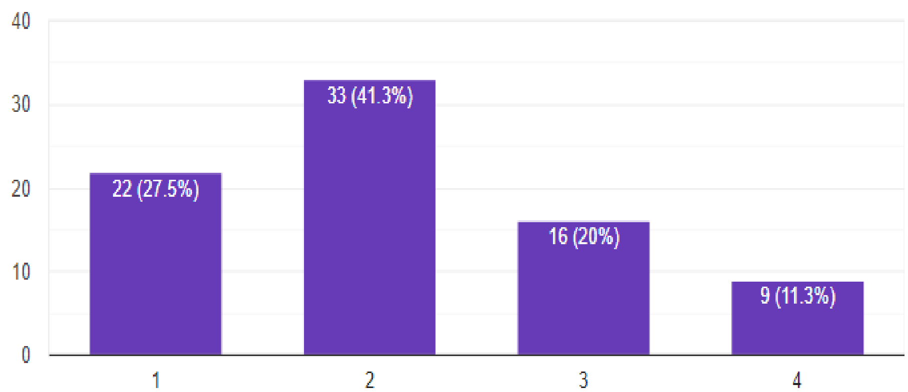
38. Inventory is managed using real-time data management which is updated by smart devices.



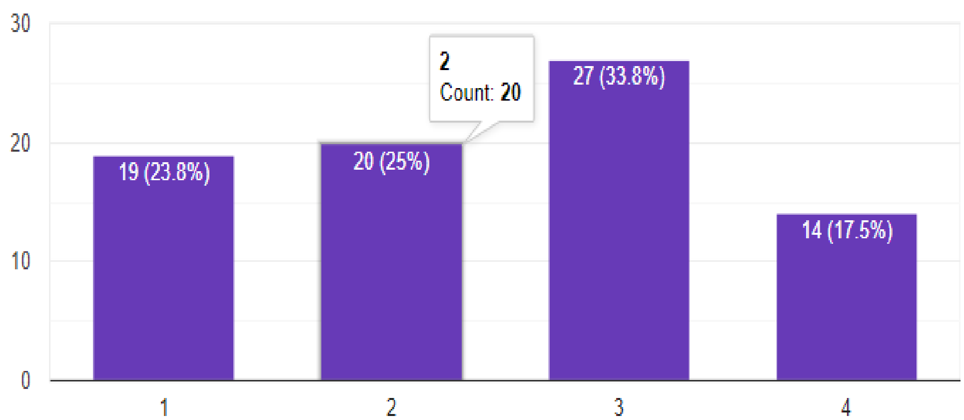
39. Supply chain is fully integrated (real time information sharing, coordination & alignment) from customer order over suppliers, production, and logistics to service.



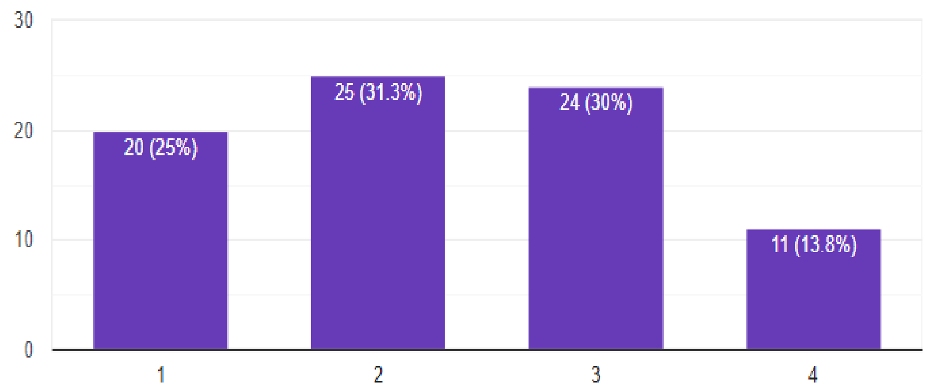
40. Site location, capacity, inventory, and operations are visible in real-time throughout supply chain and used for monitoring and optimization.



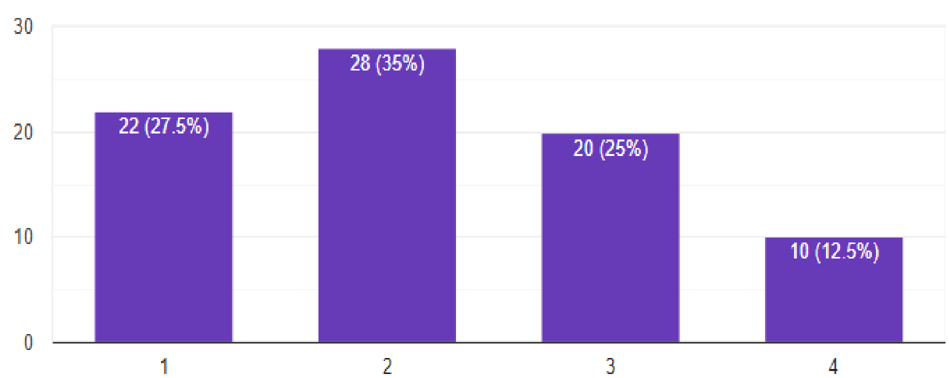
41. There is immediate response to changes in market, environment, and individual customer requirements.



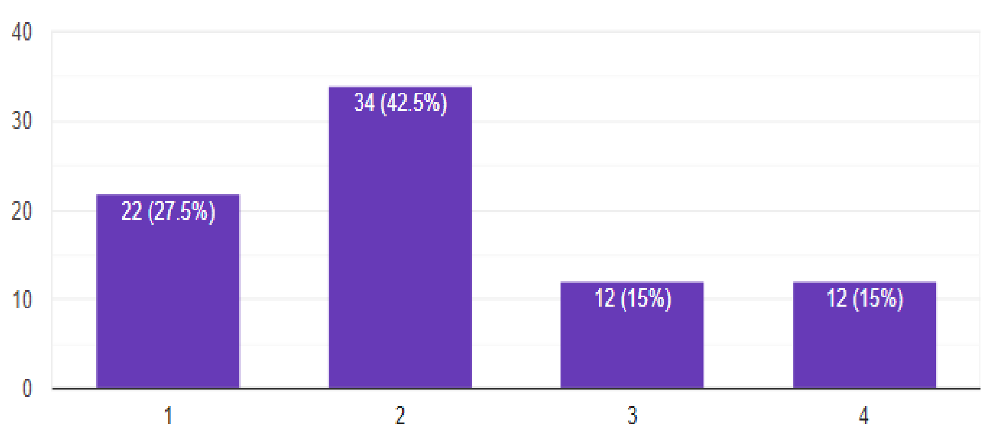
42. Multiple integrated digital and non-digital sales channels (e.g., store, sales force, web shop, sales platforms etc.) are used to sell products to customers.



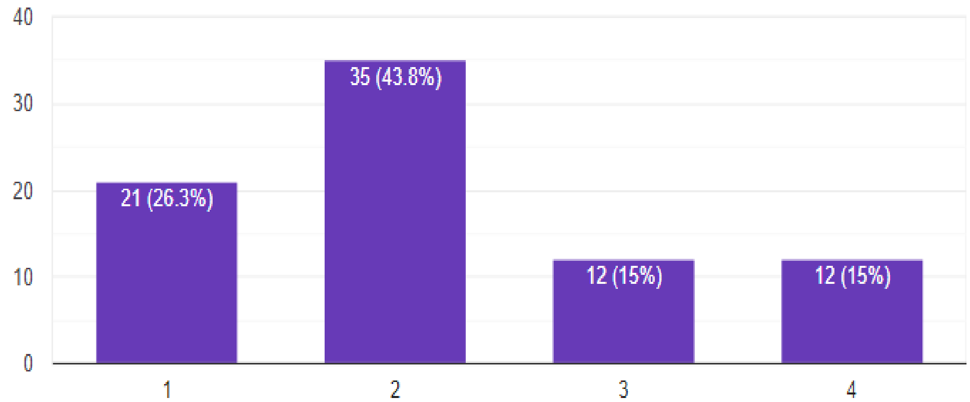
43. Multiple channels (website, blogs, forums, social media platforms, etc.) are integrated into customer interactions for communicating news, receiving feedback, managing claims etc.



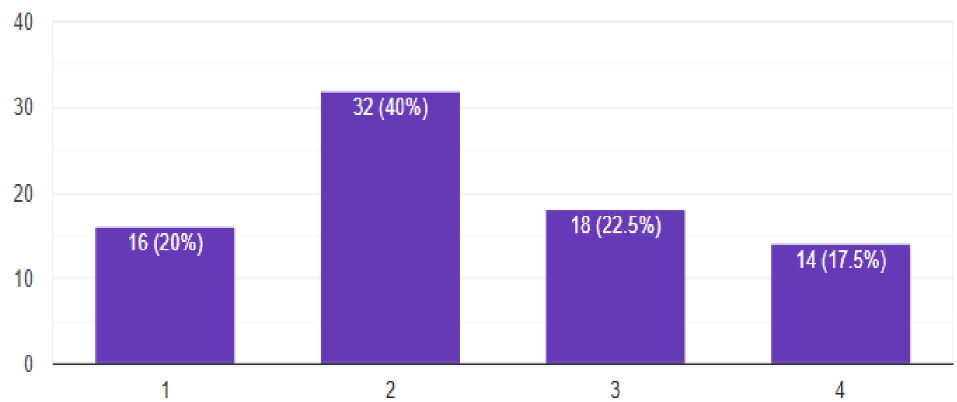
44. Sales force is supported by digital devices and can access to all relevant processes and systems at any time.



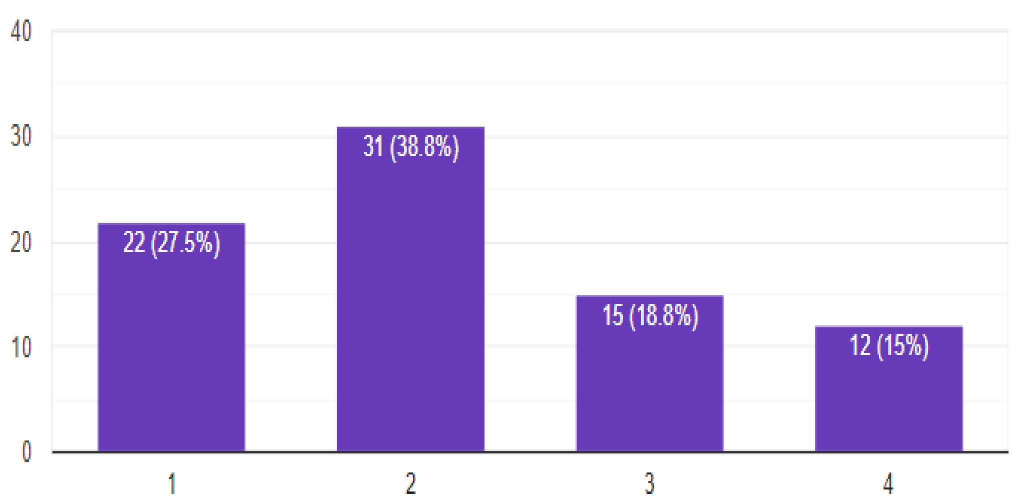
45. The firm has a sophisticated digital compliance policy.



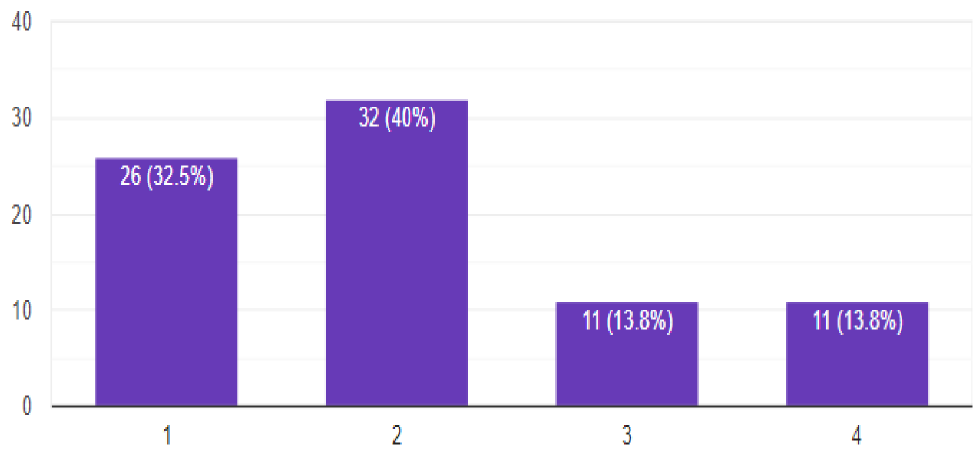
46. Data protection policies and procedures are well defined and implemented.



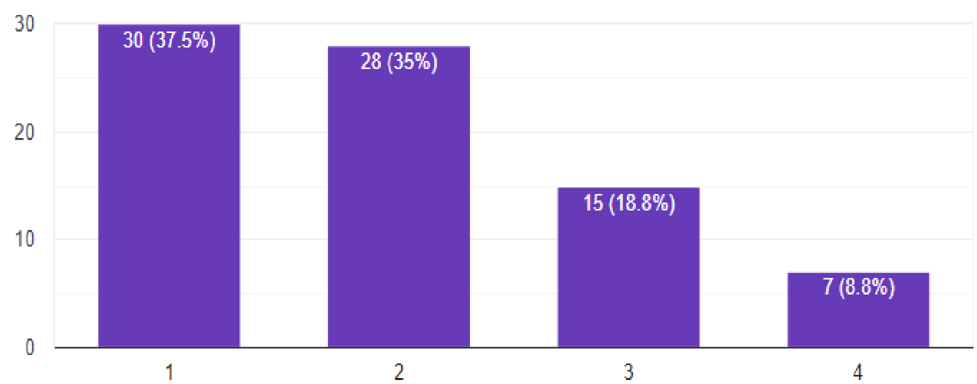
47. Production is completely integrated into the security concept and respective mechanisms are implemented to protect production from cyber threats.



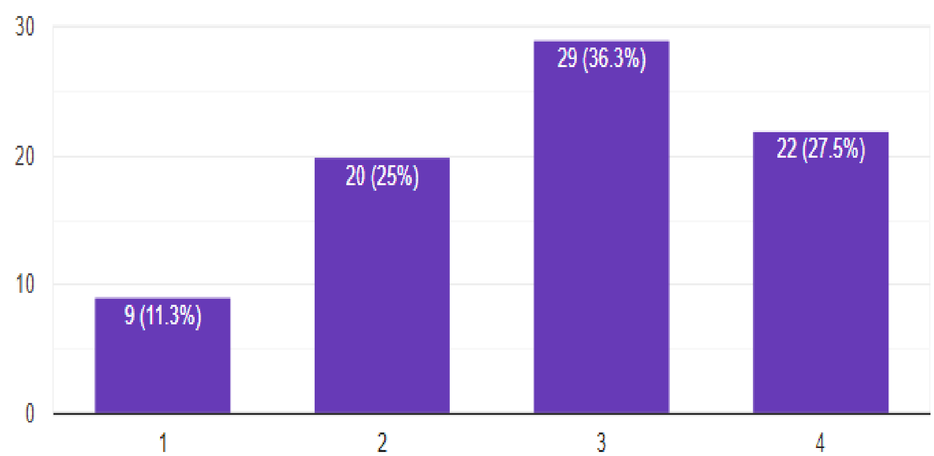
48. Risk associated with the digitization of products and production itself are completely addressed by risk management.



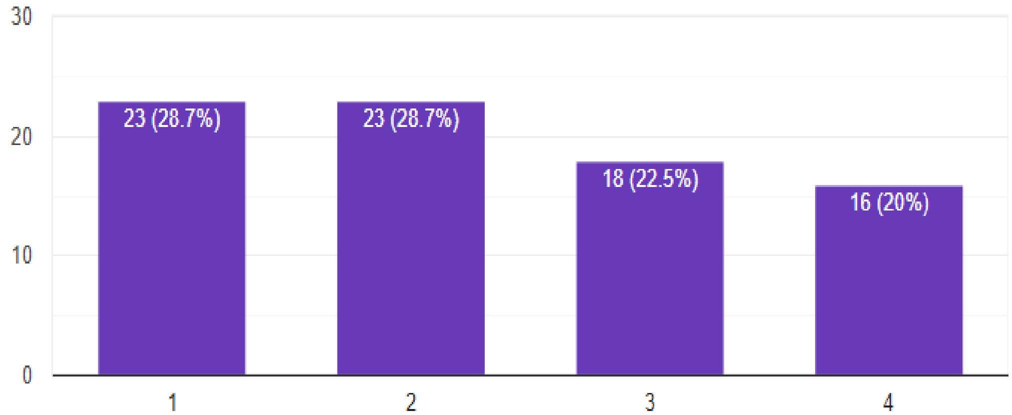
49. Intellectual property (IP) of the digital products and services is protected properly, and do not violate external IP.



50. We do not violate external IP (intellectual property)



51. Special approach for digital assets, location and the set up for the digital property (licenses, patent, IP etc.) is handled in a tax optimized way.



Annexure C – Pairwise Comparison Matrix for Industry 4.0 Drivers

Pairwise Comparison of Industry 4.0 Adoption Drivers					
Drivers	Financial	Customer Requirements	Increase Innovation	Improve Sustainability	Increase Productivity & Efficiency
1. Financial (Reduce cost)	1				
2. Customer Requirements		1			
3. Increase Innovation			1		
4. Improve Sustainability				1	
5. Increase Productivity and Efficiency					1

Annexure D – Pairwise Comparison Matrix for Industry 4.0 Barriers

Pairwise Comparison of Industry 4.0 Adoption Barriers						
Barriers	Organizational	Financial	Technological	Lack of Govt Support	Lack of clarity regarding economic benefit	Risk of security
1. Organizational	1					
2. Financial		1				
3. Technological			1			
4. Lack of Govt Support				1		
5. Lack of clarity regarding economic benefit					1	
6. Risk of security						1

Saaty Scale

Equally Important	Moderate Important	Strong Important	Very Strong Important	Extreme Important
1	3	5	7	9

Annexure E -Interview Guide Questions

1. In your expert opinion, where does our manufacturing sector stand in terms of Industry 4.0 adoption.
2. What would you think are the key issues stopping Pakistan's manufacturing sector to move forward?
3. In your expert opinion which barrier(s) are more critical in the context of Pakistan?
4. What would you think, how Industry 4.0 adoption barriers can be overcome?
5. What mechanism would you recommend that could be implemented to adopt Industry 4.0 in countries like Pakistan.
6. In your opinion, what other Industry 4.0 adoption drivers and barriers can be?

Annexure F: INTERVIEW RESULTS

Interview 1.

Industry 4.0 Drivers

Cat		Priority	Rank	(+)	(-)
1	Financial	6.6%	4	3.7%	3.7%
2	Customer Requirements	57.0%	1	22.6%	22.6%
3	Increase Innovation	2.8%	5	1.8%	1.8%
4	Improve Sustainability	15.6%	3	3.2%	3.2%
5	Increase Productivity & Efficiency	18.0%	2	7.5%	7.5%

Industry 4.0 Barrier

Cat		Priority	Rank	(+)	(-)
1	Organizational	50.5%	1	27.8%	27.8%
2	Financial	18.2%	3	7.0%	7.0%
3	Technological	3.5%	5	1.7%	1.7%
4	Lack of Govt Support	18.9%	2	6.8%	6.8%
5	Lack of clarity regarding Economic Benefits	6.5%	4	3.0%	3.0%
6	Risk of Security	2.3%	6	1.5%	1.5%

Interview 2.

Industry 4.0 Drivers

Cat		Priority	Rank	(+)	(-)
1	Financial	30.8%	2	6.6%	6.6%
2	Customer Requirements	3.7%	5	1.2%	1.2%
3	Increase Innovation	6.1%	4	2.7%	2.7%
4	Improve Sustainability	27.0%	3	5.4%	5.4%
5	Increase Productivity & Efficiency	32.3%	1	5.7%	5.7%

Industry 4.0 Barrier

Cat		Priority	Rank	(+)	(-)
1	Organizational	14.2%	3	7.9%	7.9%
2	Financial	6.2%	5	2.6%	2.6%
3	Technological	13.0%	4	3.1%	3.1%
4	Lack of Govt Support	3.3%	6	1.3%	1.3%
5	Lack of clarity regarding economic benefit	35.3%	1	15.9%	15.9%
6	Risk of security	28.0%	2	10.0%	10.0%

Interview 3:

Industry 4.0 Drivers

Cat		Priority	Rank	(+)	(-)
1	Financial	20.3%	2	11.3%	11.3%
2	Customer Requirements	8.1%	5	2.9%	2.9%
3	Increase Innovation	12.3%	3	5.0%	5.0%
4	Improve Sustainability	8.6%	4	2.0%	2.0%
5	Increase Productivity & Efficiency	50.8%	1	24.9%	24.9%

Industry 4.0 Barrier

Cat		Priority	Rank	(+)	(-)
1	Organizational	33.9%	1	17.6%	17.6%
2	Financial	16.4%	3	8.5%	8.5%
3	Technological	23.4%	2	11.7%	11.7%
4	Lack of Govt Support	8.0%	5	4.2%	4.2%
5	Lack of clarity regarding Economic Benefits	14.3%	4	5.4%	5.4%
6	Risk of Security	4.0%	6	1.4%	1.4%

Interview 4.

Industry 4.0 Drivers

Cat		Priority	Rank	(+)	(-)
1	Financial	42.3%	1	18.8%	18.8%
2	Customer Requirements	25.3%	2	14.3%	14.3%
3	Increase Innovation	6.5%	5	1.9%	1.9%
4	Improve Sustainability	17.9%	3	8.5%	8.5%
5	Increase Productivity & Efficiency	8.0%	4	3.0%	3.0%

Industry 4.0 Barrier

Cat		Priority	Rank	(+)	(-)
1	Organizational	9.1%	6	4.3%	4.3%
2	Financial	11.4%	5	6.4%	6.4%
3	Technological	19.0%	2	8.2%	8.2%
4	Lack of Govt Support	18.0%	4	4.9%	4.9%
5	Lack of clarity regarding Economic Benefits	23.8%	1	14.8%	14.8%
6	Risk of Security	18.7%	3	7.5%	7.5%

Interview 5.

Industry 4.0 Drivers

Cat		Priority	Rank	(+)	(-)
1	Financial	23.1%	2	9.9%	9.9%
2	Customer Requirements	38.7%	1	15.7%	15.7%
3	Increase Innovation	10.1%	4	6.5%	6.5%
4	Improve Sustainability	6.1%	5	2.2%	2.2%
5	Increase Productivity & Efficiency	22.0%	3	6.7%	6.7%

Industry 4.0 Barrier

Cat		Priority	Rank	(+)	(-)
1	Organizational	45.2%	1	30.5%	30.5%
2	Financial	23.1%	2	10.5%	10.5%
3	Technological	2.2%	6	1.2%	1.2%
4	Lack of Govt Support	5.8%	5	2.8%	2.8%
5	Lack of clarity regarding Economic Benefits	14.7%	3	5.6%	5.6%
6	Risk of Security	9.0%	4	3.9%	3.9%

Interview 6

Industry 4.0 Drivers

Cat		Priority	Rank	(+)	(-)
1	Financial	38.9%	1	25.4%	25.4%
2	Customer Requirements	18.3%	3	9.5%	9.5%
3	Increase Innovation	4.5%	5	1.9%	1.9%
4	Improve Sustainability	11.2%	4	5.6%	5.6%
5	Increase Productivity & Efficiency	27.2%	2	7.0%	7.0%

Industry 4.0 Barrier

Cat		Priority	Rank	(+)	(-)
1	Organizational	43.7%	1	21.0%	21.0%
2	Financial	9.4%	4	5.0%	5.0%
3	Technological	14.2%	3	6.6%	6.6%
4	Lack of Govt Support	25.9%	2	12.3%	12.3%
5	Lack of clarity regarding Economic Benefits	3.3%	6	1.3%	1.3%
6	Risk of Security	3.5%	5	1.5%	1.5%

Interview 7

Industry 4.0 Drivers

Cat		Priority	Rank	(+)	(-)
1	Financial	49.3%	1	18.4%	18.4%
2	Customer Requirements	24.1%	2	9.7%	9.7%
3	Increase Innovation	4.0%	5	1.7%	1.7%
4	Improve Sustainability	8.1%	4	2.5%	2.5%
5	Increase Productivity & Efficiency	14.4%	3	6.4%	6.4%

Industry 4.0 Barrier

Cat		Priority	Rank	(+)	(-)
1	Organizational	11.8%	4	4.0%	4.0%
2	Financial	39.3%	1	19.6%	19.6%
3	Technological	14.5%	3	7.3%	7.3%
4	Lack of Govt Support	25.0%	2	10.6%	10.6%
5	Lack of clarity regarding Economic Benefits	6.2%	5	3.5%	3.5%
6	Risk of Security	3.2%	6	1.3%	1.3%