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US Manufacturing Readiness Assesment For Industry 4.0

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US MANUFACTURING READINESS ASSESMENT FOR INDUSTRY 4.0

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ABSTRACT

Industry 4.0 is the next frontier in manufacturing evolution. Industry 4.0 is the term coined by the German government based on the research work of Henning Kaegermann. Multiple studies have been published worldwide, showing the slow or no adoption of Industry 4.0 technologies. Factors such as high costs, unproven technologies, integration, and others impacting the adoption are areas of concern.

Readiness is an important factor that impacts adoption. Understanding the current readiness for Industry 4.0 to predict future adoption levels is important. It is vital to understand the readiness of manufacturing companies to adopt Industry 4.0 technologies, as this is missing in the current research. This research assessed the Industry 4.0 readiness for US manufacturing companies.

The quantitative and correlational study measured the readiness of US manufacturing based on the company size as well as the type of manufacturing process. The readiness data was collected using an online questionnaire from manufacturing company leaders. In addition, the driving factors and obstacles were also evaluated.

The study found that Industry 4.0 Readiness is impacted by company manufacturing process but not company size. It concluded with a new readiness framework and recommendations to improve Industry 4.0 adoption.

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CHAPTER 1

INTRODUCTION

Technology creates hope as well as challenges for society. New technologies termed Industry 4.0 (I 4.0) will revolutionize the manufacturing industry in the upcoming decades. One of the common definitions of Technology Management, is a combination of disciplines that allow organizations to manage their technological fundamentals to create a competitive advantage (Systems, 1987). I 4.0 will increase productivity and profits for countries and businesses while impacting manufacturing employment. Hence, I 4.0's understanding in Technology Management is relevant.

Manufacturing in Europe and the United States has undergone two significant changes since the industrial revolution. First, the advancements in agricultural tools and the growth of factories reduced agricultural employment and migration into cities for manufacturing jobs. From 1880 to 1920, employment in agriculture in the US was reduced by 25% (McKinsey, 2017). Today, it only accounts for 2.5% of the workforce compared to 58% in 1850 (2017). Second, there has been a shift from manufacturing to service in the US and Europe. US manufacturers have increased their output by 80 percent while reducing their workforce by 17 percent since 1987 (2017). As a result, the overall share of manufacturing employment has reduced. I 4.0 is the next frontier of manufacturing evolution. I 4.0 aims to achieve efficiency gains by integrating technologies of the Internet of things, Big Data, Additive Manufacturing, Digital Twins, Machine Learning, Intelligent Control, and others.

Industry 4.0 is a term created by the German government based on the research work of Henning Kaegermann (Pascual et al., 2019). I 4.0 itself is still evolving, and there are different expert opinions on its definition. The US and other North American countries use Smart Manufacturing frequently, and Germany and other European countries commonly refer to I 4.0. The National Institute of Standards and Technology (NIST) defines it as a fully integrated, collaborative manufacturing system that responds in real-time to meet changing demands and conditions in the factory, supply network, and customer needs (NIST, 2018). Kusiak (2017) believes it integrates manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, data-intensive modeling, control, simulation, and predictive engineering. I 4.0 relies on digital technologies to gather and analyze data in real-time, providing helpful information to the manufacturing system (Lee et al., 2013). There may be a difference in opinions on the definition of I 4.0, but everyone agrees it will lead to a transformation.

Industry 4.0 is the focus of business leaders, academia, policymakers, workers, and other manufacturing stakeholders. The interconnected factories of the future will run on their own while automatically catching defects and adjusting processes. The entire supply chain will be connected from suppliers to manufacturers to customers, linked via sensors in the smart product. The industry is buzzing with the potential of I 4.0.

Several studies have highlighted the impact of I 4.0 technologies. These studies predict increased productivity, Gross Domestic Product (GDP), and reduced employment in manufacturing over the next 20 years. Price Waterhouse Coopers (PwC) forecasts a global increase of 15 trillion in GDP and a reduction of 40% of manufacturing jobs by late 2030 (PwC, 2018). A study by Oxford economics proposes significant adoption of I 4.0 by 2030, reducing 20M manufacturing jobs (Oxford Economics, 2019). According to McKinsey (2017), Internet of Things (IoT) devices will take over the industrial sector. 40%-50% of current manufacturing equipment will be replaced over 10 years.

Industry 4.0 holds tremendous promise in new applications of IoT manufacturing data with technologies of big data, cloud computing, machine learning, and artificial intelligence in the future. However, the adoption of these technologies is unpredictable due to several reasons:

- I 4.0 technologies have high costs. The initial costs of transitioning to an automated smart factory may be too high for a company. A company may need to invest in new machines, controllers, sensors, and other technologies (Kusiak, 2017). If the volume or profit does not support advanced equipment costs, people can continue to do it.
- Integration is another challenge. Companies add different software and hardware tools to their businesses over time. As the company grows, also the hardware tools and software systems. Standardizing of protocols, connectivity, and infrastructure is needed and is lagging before the full adoption of I 4.0 (Sheen & Yang, 2018).
- IoT technologies and enhancements to digital environments through cloud systems, data analytics, and machine learning are at I 4.0's core (Tuptuk & Hailes, 2018). While these tools offer great benefits, they also create avenues for security threats. The attacks on interconnected systems range from economic damage and lost production to catastrophic nationwide effects.
- Some parts of manufacturing have high-tech and automated factories, but large sections of manufacturing remain low-tech and manual. Due to complexity, volume, and margin, I

4.0 may not be feasible in many applications (Kusiak, 2017). The economics may stop some from adopting I 4.0.

Although everyone agrees with the potential of technologies, there is disagreement among researchers related to the pace of adoption (Kusiak, 2017). Some believe that impact of I 4.0 technologies will be smaller and take longer (Arntz et al., 2016). They argue that most studies on I 4.0 are grounded in technology capability, not its adoption (2017). A study by Foley (2020) on adopting automation suggests that companies are focused on I 4.0 but have progressed slowly. Along with financial resource concerns, concerns are also associated with employee availability (Foley, 2020). In 2016, Arntz et al. (2016) reviewed Frey & Osborne's (2013) initial data to add task complexity; they revised the number of jobs at risk down to 9% from 47%, based on tasks associated with jobs, slow pace of technology adoption, and workforce transition (Arntz et al., 2016). Due to technological capability and costs, even countries like Slovakia, touted as ideal for I 4.0, have been slow adopters (Grenčíková et al., 2020). Another recently published study in 2018 shows that manufacturers in West Virginia are struggling to adopt I 4.0 due to a lack of understanding and the cost of technology (Wuest et al., 2018). A study of Croatian industrial enterprises also implied that Croatian manufacturers have not started deploying I 4.0 (Veža et al., 2015). Therefore, examples of slow adoption of I 4.0 are worldwide and point to an area of concern.

The adoption of I 4.0 will vary based on requirements, technology, risks, costs, and other factors. A study from McKinsey suggests that the adoption can take 20 years longer due to known and unknown factors (McKinsey, 2017). Researchers including Frey & Osborne, Tuptuk & Hailes, Kusiak, Arntz, and organizations such as McKinsey, PWC, and Oxford economics list lack of adoption as an area of concern due to security, costs, technology capability, and others. So, it is important to understand the factors associated with adoption.

Factors

In different studies of I 4.0, the company's size has been highlighted as an important factor. Kusiak (2017) points out that larger companies have the financial and human resources to deploy I 4.0. Researchers suggest that smaller companies may be slower to adopt I 4.0 due to financial constraints (Mittal et al., 2017; Kagermann, 2014). The definition of company size can be based on revenue, employees, locations, and other factors (VDMA, 2017; Rajnai & Kocsis, 2018). For this research, company size was from US Census based on the number of employees for by North American Industry Classification System (NAICS) codes. Another highlighted factor is the type of manufacturing (Kusiak, 2017; Mittal et al., 2018). It is important to understand the difference between types of manufacturing, as processes and technology can vary.

Business leaders are vital in supporting change management (Kotter, 2011). The ensure that proper resources are allocated to the change efforts and provide the vision for the execution (Hao & Yazdanifard, 2015). Manufacturing Leaders can help gain an understanding of their company’s I 4.0 adoption.

Readiness

The Oxford Dictionary defines readiness as the "state of being prepared for something" or "willingness to do something." It is a critical precursor for successfully implementing organizational change (Kotter, 2011). It is one of the most important factors in change initiatives (Armenakis et al., 1993). The failure to establish sufficient readiness accounts for almost half of unsuccessful, large-scale organizational efforts (Kotter, 2011). As the implementation of I 4.0

will be a sizeable organizational change for the companies, the readiness of the companies for this change needs to be understood.

The study measured US manufacturing I 4.0 readiness via an online survey instrument for dimensions of smart products, digital capabilities, hardware, deployment strategy, integration, and others. The purpose was to provide a baseline for I 4.0 readiness. Some of the most used assessments are the Smart Manufacturing Systems Readiness Level (SMSRL) Tool by NIST, the VDMA tool for Industry 4.0 developed by the Mechanical Engineering Industry Association, the Uni-Warwick assessment tool created by Warwick University in collaboration with Crimson &Co and Pinsent Masons, and PWC assessment tool for Industry 4.0 readiness (NIST, 2016; PWC, 2017; VDMA, 2017; University of Warwick, 2018). They measure an organization's readiness from a technical and organizational perspective. Rajnai and Kocsis (2018) share that no standard and proven process for assessing I 4.0 readiness exists. The dimensions and data collection methods may vary, but they all aim to understand the current state of industry readiness.

This study measured the industry readiness of US manufacturing for I 4.0.

Statement of Problem

The current I 4.0 studies have been conducted by researchers from a technology capability perspective rather than adoption (Arntz et al., 2016). Multiple studies have been published worldwide, showing the slow to no adoption of I 4.0 technologies (Veža et al., 2015; Wuest et al., 2018; Grenčíková et al., 2020). Factors such as high costs, unproven technologies, integration, and others impacting the adoption are areas of concern. Therefore, it is essential to understand the factors associated with I 4.0 adoption.

Statement of Purpose

There are concerns related to I 4.0 adoption. Readiness is an important factor that impacts adoption (Armenakis et al., 1993; Kotter, 2011). Understanding the current readiness for I 4.0 to predict future adoption levels is important. It is vital to understand the readiness of manufacturing companies to adopt I 4.0, as this is missing in the current research (Mckinsey, 2017; PWC, 2018; Frey & Osborne, 2013; Kusiak, 2017). This research focused on assessing the I 4.0 readiness for adoption.

The study aimed to measure the I 4.0 readiness of US manufacturing. It helped to understand the pace of adoption. The research results benefit the stakeholders, including policy makers, manufacturing leaders, academia, companies, and others. It may also apply to other countries and industries. Finally, it helped future researchers develop strategies to accelerate the adoption of I 4.0.

Research Questions

Research Question 1(RQ1): What is US manufacturing companies' current I 4.0 readiness level?

The question aimed to answer the level of readiness. To adopt smart technologies in the future, companies should have efforts planned or ongoing in areas of technology and organization. Companies should be enhancing the technical areas of connectivity framework, big data, cloud computing, etc., and be engaged in organizational areas of strategy, employee skills, equipment, and others. These factors measure the current level of adoption of technologies and preparedness of organizational factors to establish a baseline for the current state of I 4.0.

Research Question 2 (RQ2): Does readiness vary by Organization’s Size and Type of Manufacturing?

Organization Size and Type of Manufacturing are critical factors impacting adoption (Kusiak, 2017; Mittal et al.,2018). This question targeted to understand whether overall readiness varied based on these factors.

Hypothesis 1

Ho_1: There is no statistically significant difference in readiness for Industry 4.0 adoption between company sizes.

Ha_1: There is a statistically significant difference in readiness for Industry 4.0 adoption between company sizes.

Hypothesis 2

Ho_2: There is no statistically significant difference in readiness for Industry 4.0 adoption among the type of manufacturing process.

Ha_2: There is a statistically significant difference in readiness for Industry 4.0 adoption among the type of manufacturing process.

Research Question 3 (RQ3): What is the level of concern related to various Industry 4.0 technology challenges?

This RQ measured the concern related to cyber security, costs, technology capability, system integration, and employee skills.

Research Question 4 (RQ4): What are the obstacles to adopting Industry 4.0?

It is important to understand the obstacles related to the adoption, as that can help future researchers identify the areas of improvement.

Research Question 5 (RQ5): What are the main factors influencing the adoption of Industry 4.0?

The main factors driving the adoption of I 4.0 can help future researchers accelerate the adoption by supporting those factors.

Methodology

The study was quantitative, descriptive, and correlational. The industry readiness data was collected via an online survey questionnaire. By studying the sample, survey research offers a quantitative or numeric description of a population's trends, attitudes, or opinions (Creswell & Creswell, 2018). Descriptive analysis depicts the phenomenon, and correlation analysis tests the relationship between the independent and dependent factors.

Population

The study's target population was US manufacturing companies' business leaders. Business leaders are vital in supporting change management (Kotter, 2011). They provide the vision, direction, and resources for organizational change (Kotter, 2011). Effective leadership is the key to successful change (Hao & Yazdanifard, 2015). Manufacturing Leaders can help gain an understanding of their company's readiness. The population is the leaders of manufacturing organizations, including Vice Presidents, Directors leading various functional groups, Plant, and Functional Managers within manufacturing organizations. This target population provided information on company readiness for strategy and technical factors. In addition to providing a holistic view, their decisions will shape the future of adoption as they are the decision-makers for manufacturing functions. It included all manufacturing processes, including continuous, batch, repetitive, and others across all manufacturing industries.

Sample

The sample was a subset of the population of manufacturing leaders. Creswell & Clark (2007c) suggest that sampling methods maximize efficiency and validity and be consistent with the aims and assumptions inherent in using either method, irrespective of the methodology employed. Gurung (2019) states that convenience sampling is acceptable in a new study area. The non-probabilistic technique of convenience sampling is appropriate for this research.

Data Collection

ISU's Internal Review Board (IRB) Process was employed to protect human subject rights and welfare. The study used Qualtrics, an online tool, to collect the data from the sample. Distributing the survey to different subjects identified via different platforms can reduce the convenience sampling bias (Etikan et al., 2016). The participants were selected through the author's LinkedIn network, the Society of Manufacturing Engineers (SME), and the Kansas City American Society of Quality (ASQ). The survey was conducted via an online questionnaire over 6 weeks. An IRB-approved email was sent inviting the subjects to participate in the questionnaire via Linked in and ASQ local chapter distribution list. Also, the survey was posted on SME's blog. All incomplete or irrelevant surveys were discarded from the data set prior to analysis.

Survey Instrument

Readiness for I 4.0 is an essential factor. Rajnai and Kocsis (2018) share that currently, there is no standard and proven process for assessing I 4.0 readiness. The VDMA Industry 4.0 readiness assessment is a robust instrument. Researchers have recommended and used it to perform exploratory I 4.0 readiness assessments (Basl & Kopp, 2017; Berhard & Harmoko, 2020; Maisire & Van Dyk, 2019). The survey instrument was modified to align with the research goals. A panel of subject matter experts validated the survey. The reliability of the survey instrument was confirmed with Cronbach alpha statistic with a pretest of 30 samples.

Variables

Various descriptive statistics were generated to explain the phenomenon. The percentage of different demographics factors of the role, company size, knowledge of the industry, and manufacturing process helped gain insights into the sample. The second part of the research tested the relationship between Independent Demographic variables of the Company Size and Manufacturing Type and the Dependent variable of Average readiness level. Paired t-test was used to compare average readiness levels between different factors. Also, linear Regression tests the hypothesis between the Independent Variables (IV) and Dependent Variables (DV) listed in table 1. Creswell & Creswell (2018), Creswell & Clark (2007c), Donalek and Soldwisch (2004), and others have suggested that an alpha of .05 is robust for research. The tests were conducted at the alpha of .05.

Table 1

Study Variables Table

Name	Type	Data Type	Collection Method
Type of Manufacturing	Independent	Nominal (Category)	Single demographic question.
Company Size	Independent	Nominal (Category)	Single demographic question.
Level of readiness	Dependent	Interval	A set of Likert-type questions.

The research findings were concluded based on the results of hypotheses testing between the dependent variable of readiness and independent variables.

Assumptions

- As this was quantitative research, Quantitative researchers assume that the nature of reality is measurable (Creswell & Creswell, 2018). In the positivist view, statistics and experiments reveal how society operates (Mertens, 2005). This research followed the quantitative methodology assumptions.
- The research also assumed that the study subjects have a basic understanding of I 4.0.
- The selected subjects were truthful in the survey responses.

Limitations

- Data was only self-reported and limited to individual perceptions. I 4.0 is evolving and changing, and there is no standard definition. Therefore, the personal views of the I 4.0 application may vary.
- The study relied on an online questionnaire to collect the data. Online survey limitations are associated with response bias and verifying the accuracy of participants’ responses (Pedersen & Nielsen, 2014).
- The researcher could not verify the survey responses with independent data due to a lack of in-person accessibility.
- This study has limited generalizability due to convenience sampling. The study's results are limited to leaders participating in the research.
- The data is collected at a single point in time and does not capture any changes in readiness over time.

Delimitations

- The research was limited to US manufacturing.
- The technologies related to communication and the transfer of information were included. Other technologies, such as additive manufacturing, advanced robotics, etc., were not considered.
- The research was limited to leaders of manufacturing organizations.

Terminology

- CC - Cloud Computing is Internet-based computing where the shared resources (e.g., storage and computing facilities, software, data, applications, etc.) are accessed and used on-demand (Qu et al., 2019).
- CPS – Cyber-Physical Systems is a wireless-based control system that connects physical objects on the factory floor with a hardware device to virtual models (Qu et al., 2019).
- Industry 4.0 – 4^{th} Industrial revolution based on inter-connected devices. Industry 4.0 relies on digital technologies to gather data in real-time and analyze it, providing helpful information to the manufacturing system (Lee et al., 2013).
- IoT – The Internet of things is a network of sensors that collect manufacturing process data and cloud connectivity for insights about the performance of the manufacturing processes (Qu et al., 2019).

CHAPTER 2

LITERATURE REVIEW

Introduction to Industry 4.0

National Research Council defines that Technology Management links engineering, science, and management disciplines to plan, develop, and implement technological capabilities to shape and accomplish the strategic and operational goals of the organization (National Research Council, 1987). Industry 4.0 (I 4.0) combines various technologies to improve a company's manufacturing processes. Hence, it is crucial to understand its effectiveness from a Technology Management aspect. Several studies have been published on I 4.0 implementation. These studies have been conducted from the perspective of technology potential, not its adoption (Arntz et al., 2016). There is also apprehension regarding the adoption-related to complexity, standardization, costs, and security (Kusiak, 2017). This study measured the manufacturing readiness for I 4.0 adoption.

Since the first industrial revolution of the late 1700s, the manufacturing industry has transformed through technology. The transition from hand power to steam and waterpower in the late 1700s revolutionized the textile, iron, mining, and agriculture industry. In the late 1800s, productivity increased through the adoption of electrification, mass production, and other techniques. The 1970s saw higher adoption of automation and robots on factory floors, leading to increased productivity, and reduced manual jobs and costs. Over the last few decades, manufacturing continued with extensive integration of new technologies leading to the digitization of several processes and the creation of inter-connected global Supply chain networks. I 4.0 is the evolution of the paradigm shift that started in the 1970s by integrating machines and computer technologies. However, it differs from previous changes in that I 4.0 is about continuous monitoring of manufacturing process data from the factory floor.

Since the integration of computer technologies into manufacturing, various terms, including flexible systems and manufacturing cells, computer-integrated manufacturing, intelligent manufacturing, automated cells, and others, have been used to describe the technology in manufacturing (Kusiak, 2017). Currently, there is no agreed-upon definition of I 4.0. The National Institute of Standards and Technology (NIST) defines it as a fully integrated, collaborative manufacturing system that responds in real-time to meet changing demands and conditions in the factory, supply network, and customer needs (NIST, 2017). It integrates manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, data-intensive modeling, control, simulation, and predictive engineering (Kusiak, 2017). It is a set of manufacturing practices using networked data and information and communication technologies (ICTs) to govern manufacturing operations (Davis et al., 2015). Hermann et al. (2016) defined it as cyber-physical systems, the internet of things, services, and smart factories. From an engineering view, I 4.0 is an intensified application of advanced intelligence systems that enable the fast manufacturing of products by responding to product demand, and optimizing manufacturing production and supply chain networks in real time (Frank et al., 2019b). Using sensors and communication technologies to capture data at all manufacturing stages, I 4.0 increases production while reducing errors and waste (Zheng et al., 2018). I 4.0 cannot be limited to thinking about robotics and production automation because it is the digitization of business processes; it involves procurement of materials and how the product "gets" through production and is delivered to the customer (Roblek et al., 2016). There are several definitions of I 4.0 and opinions on its capabilities. Figure 1 shows the I 4.0 technologies for this research. I 4.0 is the application of the following technologies in manufacturing:

- Internet of things.
- Cyber-physical systems.
- Cloud computing.
- Big Data Analytics.

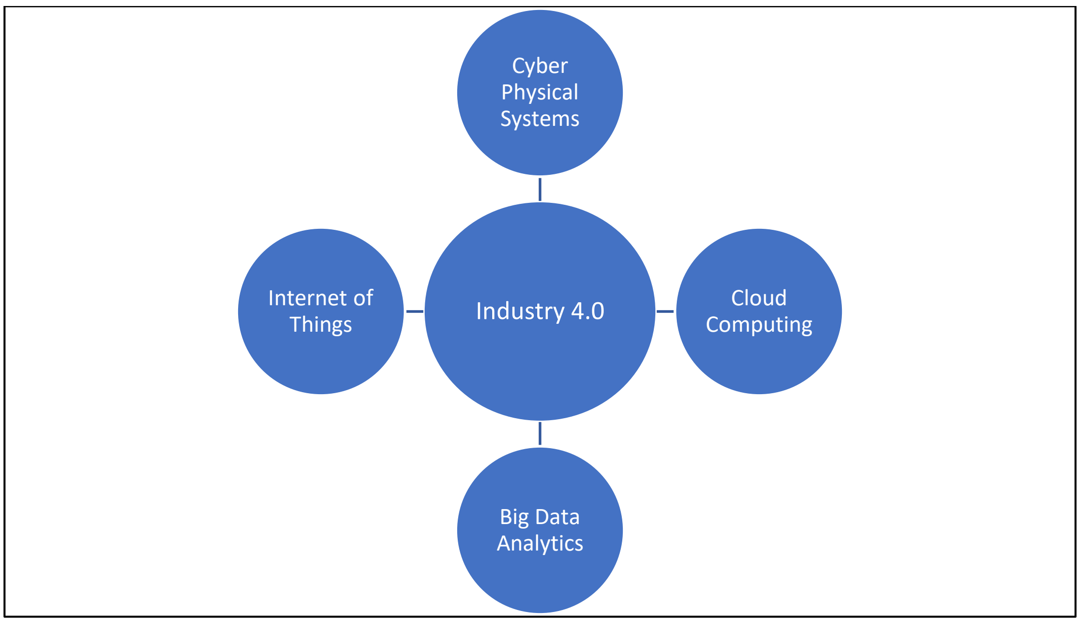

Figure 1. Components for I 4.0 for the research.

Industry 4.0 and Smart Manufacturing

In addition to different definitions associated with I 4.0, Smart Manufacturing is also a term for integrating technologies into manufacturing. It is the movement of innovations culminating and maturing to transform the energy and manufacturing sectors through digital innovations embedded in a global interchangeable value chain (Foley, 2020).

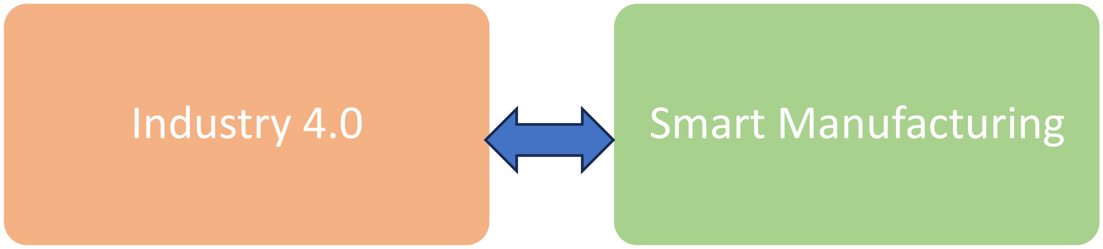

Figure 2. Industry 4.0 and Smart Manufacturing

It relies on digital technologies to gather data in real-time and analyze it, providing helpful information to the manufacturing system (Lee et al., 2013). The vision of Smart Manufacturing and I 4.0 is the same, integration of interconnected manufacturing processes. Pascual et al. (2019) emphasized that Smart manufacturing and I 4.0 should be synonyms. The US and other North American countries use Smart Manufacturing frequently, and Germany and other European countries commonly refer to Industry 4.0. For this research, Smart Manufacturing and Industry 4.0 are considered the same as shown in figure 2.

Industry 4.0 Framework

Kusiak (2017) proposes a general concept of an intelligent manufacturing enterprise, as illustrated in Figure 2. It includes two primary layers, the manufacturing equipment, and the cyber layers, linked by the interface. The manufacturing equipment has its intelligence, while the Cyber layer provides system-wide intelligence. In an I 4.0 environment, operators, equipment, and product communicate with each other. Different systems such as machines, conveyors, AGVs, and others are connected and communicate regarding the process in a smart factory. The raw material, WIP, and finished goods also have intelligence built to communicate information back into the system. The product is also an information carrier. It allows the systems to work independently by exchanging information with minimal human intervention. This concept of machines communicating and controlling each other is known as cyber-physical systems. For example, a lathe measures and communicates the information from the machining process to other devices. This may include information such as the condition of raw material, time to complete, condition of the machine itself, and others. The IoT devices communicate this information in the smart factory. Based on the information shared by Lathe, the next machine can plan operation, the conveyor system can plan the transportation of batches of raw materials to the machine, and the machine condition information can help plan the maintenance activity to eliminate unplanned downtime. It also allows for predictive and automated maintenance while reducing downtime. In I 4.0, all the components continuously exchange information and make decisions based on the information. It allows the systems to be highly flexible, allowing for custom or on-demand interconnected manufacturing.

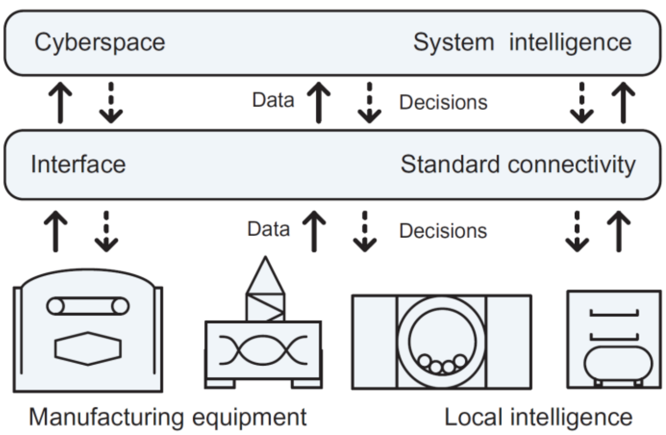

Figure 3. Smart Manufacturing Enterprise.

Note. From Smart Manufacturing by Kusiak, A, 2017, *International Journal of Production Research*, https://doi.org/10.1080/00207543.2017.1351644. Copyright 2017, Taylor & Francis.

Factors driving Industry 4.0

Technology adoption in manufacturing has been rising for the last few decades. The United States Manufacturing Technology Orders (USMTO) report published by Association for Manufacturing Technology (AMT) reported technology orders through October 2022 as the best year ever (AMT, 2022). The investment in technology is increasing in manufacturing as shown in figure 4. The number of robots installed worldwide has doubled since 2010 (Oxford Economics, 2019). Robots are used extensively throughout China, Korea, Taiwan, India, Brazil, Poland, and others. Every third robot is installed in China, the largest robot market (Oxford Economics, 2019).

Several factors are driving this explosive growth in new technologies. First, technologies are becoming cheaper than humans. For example, robot costs will reduce by 65% from 2015 to 2025 as labor costs continue increasing simultaneously (Oxford Economics, 2019). Second, technology is rapidly becoming more capable. Technological advancements in machine learning and connectivity have and will continue to enhance machine capabilities. Third, global demand is rising, and there is intense pressure on companies and countries to keep their costs low. Finally, companies are integrating more technology to produce products faster and cheaper.

Technology increase will provide several benefits to the global economy. First, the indication is that it can increase the productivity between 0.8 and 1.4 percent of global GDP annually if human labor replaced by automation rejoins the workforce and is as productive as it was in 2014 (PWC, 2018). Second, I 4.0 increases scale and speed. For companies, deploying I 4.0 delivers benefits in labor cost savings and other performance-enhancing ways (PWC, 2018). I 4.0 enables firms to be close to customers and predict maintenance needs while reducing the cost of operations and extending the life of assets.

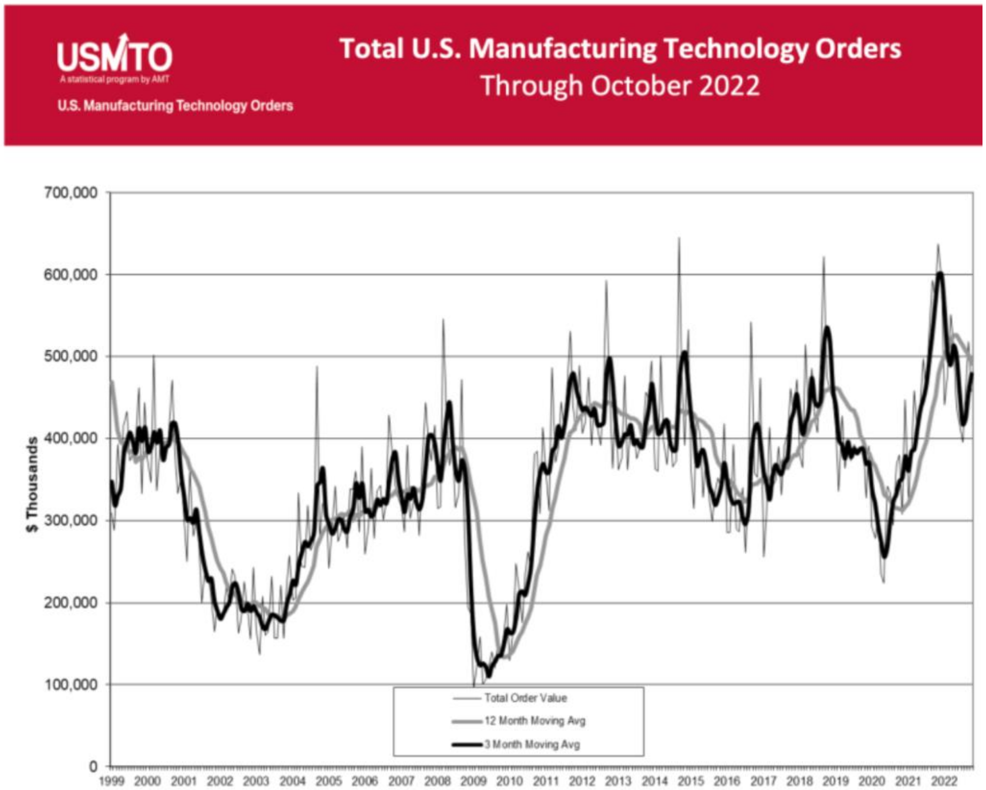

Figure 4. US Manufacturing Technology Orders.

Note. From Manufacturing Technology Orders Through October 2022 on Pace with Best Year Ever by AMT, 2022. https://www.amtonline.org/article/manufacturing-technology-orders-through-october-2022-on-pace-with-best-year. Copyright 2022, AMT

Industry 4.0 Technologies

Industry 4.0 is not one technology but a combination of several emerging technologies. Kusiak (2017) and Kagermann (2014) highlight that the connectivity of industrial devices is essential for I 4.0. The ability of various devices to communicate with each other is at the core of I 4.0 (Kusiak, 2017; Kagermann, 2014). It is not about collecting data but adapting based on it (Mittal et al., 2018). Sensors communicate the data from machines via the Cloud connectivity solutions deployed at the factory level. Various technologies leveraging wired and wireless connectivity enable this data flow and analysis. It allows monitoring and managing processes remotely and changing production plans quickly, in real-time, when needed. Some of the main technologies are:

Internet of Things - IoT integrates smart sensors and computing through wireless communication. It is a network of sensors that collect manufacturing process data and cloud connectivity for insights into the performance of the manufacturing processes (Qu et al., 2019). Interconnection allows for the capture and sharing of data between machines in real-time. This information captured in real-time and acted upon quickly can reduce downtime, improve efficiency, reduce inventory, and other benefits. As a result, manufacturing companies can reduce costs and increase productivity, meaning a more tangible return-on-investment for adopting solutions. IoTs are smart sensors embedded in Supply chain equipment and Smart products.

Cyber-Physical System - CPS is a wireless-based control system that connects physical objects on the factory floor or system with virtual models. CPS is about the intersection, not the union, of the physical and the cyber (Qu et al., 2019). It is not sufficient to separately understand the physical and computational components. These intelligent control units can autonomously communicate and exchange self-optimized information with other objects. These production unities are called Cyber-Physical Systems (CPS). In summary, CPS are the mediums that connect the Supply Chain and product components to information systems.

Cloud computing - CC is Internet-based computing where shared resources (e.g., storage and computing facilities, software, data, applications, etc.) are accessed and used on demand. It answers the need for data management with data explosion in manufacturing. The main features of CC are sharing resources such as manufacturing software, facilities, and high-performance computing to improve performance, data analytics, energy consumption, etc. (Qu et al., 2019). CC, combined with manufacturing, has given rise to a new cloud-based manufacturing model. All manufacturing resources and capabilities are virtualized and encapsulated as managed, allocated, and on-demand through the cloud.

Big data and Analytics consist of data gathering from systems and objects, such as sensor readings. Analytics – e.g., data mining and machine learning, is considered one of the most critical drivers of I 4.0 and a key source of competitive advantage for the future. Big Data and Analytics is the process of reviewing the data acquired by IoTs in processes. The main components are Discover Knowledge, Prediction, and Optimization (Qu et al., 2019). Big Data analyzes the vast amount of data gathered by IoTs to make better-informed business decisions. It is used in manufacturing and maintenance to improve production processes and service strategy (Qu et al., 2019). Big data is the tool that gathers and analyzes the data from Smart Supply Chain and Products.

IoT, Cloud Computing, CPS, and Big data analytics technologies work together to enable I 4.0. IoT aims to solve communication issues among all objects and systems in a factory. CPS provides the interaction between physical and information systems, while cloud services provide easy access to information and services. Lastly, big data and analytics are the key enablers to advanced applications of I 4.0 since the system's intelligence depends on the large amount of data accumulated (big data) and the capacity to analyze with advanced techniques (analytics). Thus, focusing on the central element of I 4.0. In addition, other technologies such as additive manufacturing, simulation, artificial intelligence, and others are also considered part of the I 4.0.

Industry 4.0 Characteristics, Features, and Factors

A literature review of over 80 articles published since 2013 conducted by (Mittal et al., 2018) identified 27 characteristics. Based on these articles, the authors identified 5 main characteristics of I 4.0. The amount of research implies that the SMs fundamental functions, including self-sensing, self-adaptive, self-organizing, and self-deciding, make the manufacturing system smarter, driven by CPS, big data, AI, and other advanced technologies (Mittal et al.,2018). The characteristics, features, and enabling factors of I 4.0 are (Mittal et al.,2018).

The significant characteristics of an intelligent manufacturing system are:

- Context awareness means that the system should be able to know about its present state.
- Modularity is the property by which a unit can be decomposed into components combined to form different configurations.
- Heterogeneity considers the diversity and dissimilarities in the units and components.
- Interoperability is the characteristic of which system units can exchange and share information.

Technology Features of are:

- Intelligent control is how manufacturing systems respond to events.
- Energy-saving/efficiency to cause minimum environmental footprint and make the products and processes more economical, social, and environment-friendly.
- Cybersecurity. As the basis for I 4.0 is digitization and data-based services, security is an integral technology for SMS.
- Data analytics turns data volume, variety, velocity, and veracity into actions and insights within a manufacturing system.

- Predictive analytics finds results from the variables, and data mining allows the examination of the data.
- CPSs/CPPSs are computer algorithms technologies used to solve and work with physical mechanisms/components.
- The IoT enables communication between physical and Internet-enabled devices and can improve existing manufacturing systems.

Enabling Factors are:

- Law and regulations. Various laws and regulations, such as IP, and labor laws, will have to be reformed.
- Data sharing systems and standards. Universally standardized information models are needed to exchange data on various devices.
- Technical education and training. Trained resources will be needed to support I 4.0 systems.

Vertical and Horizontal Integration

The goal of I 4.0 is to create interconnected supply chain processes via the complete digitization of a company's operations (Frank et al., 2019b). All functions and operations of a company are integrated vertically and horizontally by connecting vendors, partners, and distributors. Data is transferred automatically within each group, and autonomous decisions meet customer orders.

Vertical integration combines IT systems at various hierarchical production and manufacturing levels, as shown in figure 5 (Rojko, 2017). To reach vertical integration, the first step at the shop floor is the digitalization of all physical objects and parameters with sensors, actuators, and Programmable Logic Controllers (PLC) (2017). Supervisory Control and Data

Acquisition (SCADA) gathers production control and diagnosis data on the shop floor. At the managerial information layers, Manufacturing Execution Systems (MES) obtain data from SCADA, providing production status to the Enterprise Resource Planning (ERP) system. The production orders' information also flows inversely (downstream) from ERP to MES and then to SCADA, aiding to organize the enterprise resources into manufacturing orders through integration (Pascual et al., 2019). Therefore, vertical integration provides more transparency and control of the production process and helps to improve the shop floor decision-making process.

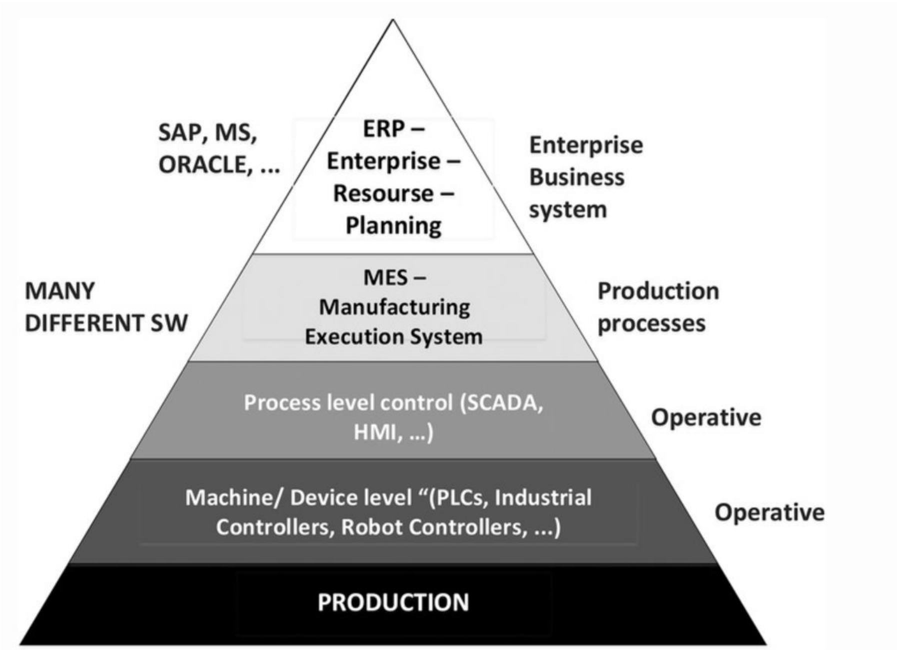

Figure 5. Vertical Integration model of I 4.0.

Note. From Industry 4.0 Concept: Background and Overview, by Rojko A. *International Journal of Interactive Mobile Technologies.* https://doi.org/10.3991/ijim.v11i5.7072. Copyright 2017. ECPE European Center for Power Electronics

Horizontal integration in figure 6 combines IT systems for and across the various production and business planning processes (Pascual et al., 2019). Between these various processes are flows of materials, energy, and information. Horizontal integration is about digitization across the total value and supply chain, whereby data exchanges and connected information systems take center stage, as shown in figure 5 (Pascual et al., 2019). This considers all the links in the value chain and the developed relationships, establishing and maintaining networks that create and add value.

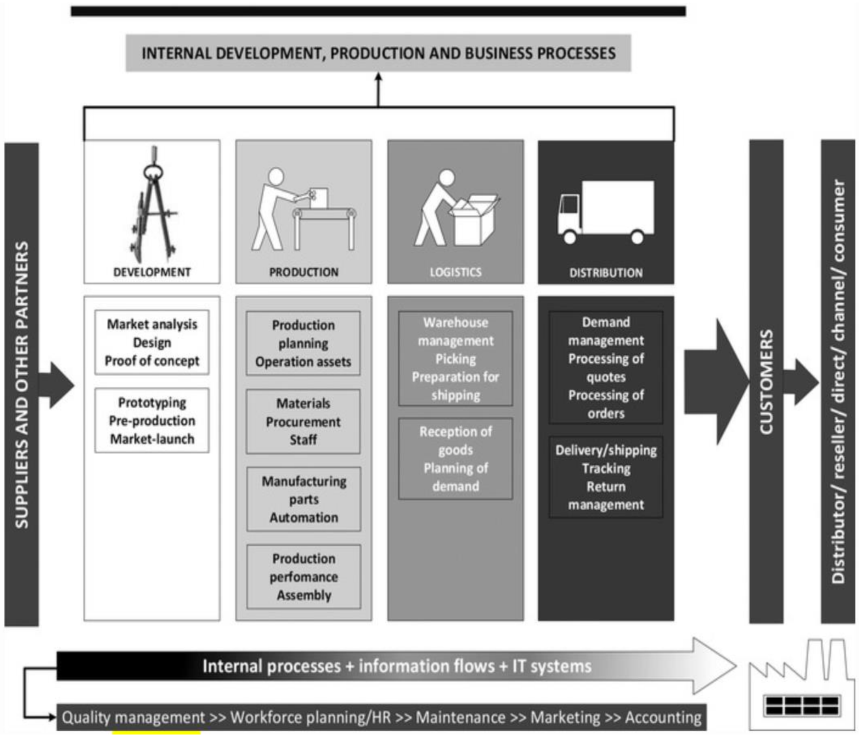

Figure 6. Horizontal Integration model of Industry 4.0.
Note. From Handbook of Industry 4.0 and SMART Systems, by Pascual, D. G., Daponte, P., & Kumar, U., 2019. CRC Press. Copyright 2019, CRC Press.

I 4.0 also leads to redesigned products and services by embedding technology to monitor their use. These are known as smart products, where the product is a source of information for the processes. It tracks the product through the entire value chain. The manufacturers and distributors can adjust their products, services, and processes to ever-changing customer needs. This feature creates a closer interaction with the customers. As a result, the value chain becomes more responsive, providing data from the product to service the customer directly and more intimately (Foley, 2020).

Uncertainty in I 4.0 Adoption

Researchers have also raised some concerns associated with technology capabilities and advancements. For example, the research related to job loss considers the potential technology capability of future technologies than the actual adoption (Arntz et al., 2016). The actual pace of technology adoption and implementation may be much faster or slower (Arntz et al., 2016).

Limitations of Technology

The future of technology is difficult to predict. Technology is constantly changing and evolving as it interacts with society. Smart Technology adoption will play a key role in its success. Based on the study by PWC, manufacturing is the second most vulnerable industry to be impacted after transportation. The overall impact felt may be the highest for manufacturing as the sector (with an estimated automatability of 45%) has a median employment share across countries of 14%, compared to only 5% in transport and storage. Some of the critical areas of task-related concerns are (Frey & Osborne, 2013):

- Machines have to evolve to execute unstructured tasks. Algorithms work well in set patterns but do not react well when new situations arise, or processes break down.
- There are also limitations in identifying objects in a cluttered field of view. However, this limits robots' ability to manipulate tasks and handle irregular objects.
- Another challenge is the robot's ability to react to failures; the simple task of adapting to a minor defect from the previous operation in a manufacturing line or a missing tool can be daunting for machines.
- The difficulties of planning the sequence of actions required to move from one place to the other, limits the manipulation of objects. Most industrial manipulation uses workarounds to these challenges, but these approaches have a narrow application.

- Social intelligence is essential in many work tasks, such as negotiation, persuasion, and care. Although some algorithms and robots can mimic human interaction, recognizing human emotions is still challenging.

Some of the challenges highlighted above relate to technology capabilities, such as perception and manipulation, which are unlikely to be fully resolved in the next decade (Frey & Osborne, 2013). Although, some of the sophisticated algorithms and developments in machine learning building upon big data may now allow many non-routine tasks to be automated. Automating tasks involving complex perception and manipulation, and emotional intelligence is still uncertain.

<u>Cost of Technologies</u>

A combination of complexity, volume, and margin can rule out the use of I 4.0 in many applications. If the profit generated or the volume is too low, the costs of I 4.0 will not be supported, and the factory may never adopt I 4.0. Smart machines also cost more, and only some industries can support these costs. Technologies will get cheaper over time, but the cost and benefit analysis may keep several companies from adopting I 4.0.

The initial costs of transitioning to a smart learning factory may be too high for a company. A company may have to invest in new machines, controllers, and sensors to benefit from a connected learning environment. This overhaul may be cost-prohibitive for businesses. Although some of these costs will reduce over time, the overall timeline is difficult to predict. The adoption of automation will vary based on requirements, skills, jobs, and other factors. The pace of adoption could take 20 years longer due to other factors (Mckinsey, 2017).

System Integration

Companies add different software and hardware tools over time. As the company grows, consequently, the number of tools grows too. Manufacturing companies consist of several processes. These processes produce various outputs. The processes are Quoting, Purchasing, Inventory Management, Planning and Scheduling, Shop floor management, Quality, Data collection, Job costing, Accounting, and others. In I 4.0, integrating all the different processes is important (Chignell, 2017). The business must have the following for integration (Chignell, 2017):

- A common software environment
- A common data management system
- A common communication method

Systems integration in manufacturing involves combining multiple systems, such as Production CNC machines, MRP, Controllers, Material handling systems, Robotics, and others, to manage and maintain one or multiple production units. The level of system integration varies from situation to situation. Systems integration has been at the forefront of the IT sector in the past years. The definition of System integration can also vary. Chignell (2017) defines systems integration as joining the functions of a set of subsystems, software, or hardware to result in a unified system that supports the requirements of an organization. Another definition of systems integration is: "the assembling of various hardware (such as computers and telecommunication systems), software (such as accounting, desktop publishing, and personnel management), and human interfaces to accomplish a specific goal" (Chignell, 2017). However, a more straightforward definition is: "A service to make user's isolated computers link each other and make them much easier and more useful" (Bakar, 1970). Integrated systems also do have some disadvantages (Sinha, 2017):

- Difficult to build (incompatibility issues): There can be multiple hardware and software platforms, and developing the initial build can be complex.
- Maintenance and upgrade costs: Due to the interlinkage of various components, maintenance can be a challenging task. Managing upgrades can also be daunting as hardware and software changes may be needed.
- Expensive: System integration can be expensive as it may require changing or creating new hardware and software.
- Time constraints: It can take several months to a few years.
- Changing production models: Integrated models do not handle significant changes in production models well.

New technologies can extend these automation capabilities to the production floor. For example, the vast amounts of data production processes, robotics, and edge devices provided to centralized ERP systems, maintenance schedules, demand planning, and reporting can all be completed without human intervention.

As pointed out earlier, the current systems lack the standardization needed to achieve the full integration required for automation. Although it may be possible to automate tasks conceptually, standardization in protocols, connectivity, and infrastructure is badly needed before full integration becomes a reality.

Security

Manufacturing systems are going through rapid evolution toward digitization. The gap between physical and digital manufacturing is slowly going away. Internet of Things (IoT) technologies, coupled with enhancements to digital environments through greater use of cloud systems, data analytics, and machine learning, is the future of manufacturing processes. While these tools offer great benefits, they also create new avenues for security threats (Tuptuk & Hailes, 2018). The attacks on interconnected systems range from economic damage and lost production to catastrophic nationwide effects through injury and loss of life.

In the integration design, the security of the processes needs to be embedded. Also, the systems must be flexible and continually evolve to keep up with new threats. One of the avenues that can help with security is the standards created by governmental and regulatory bodies. Intrusion detection systems must be embedded in various systems, as integrated systems contain multiple software and hardware components. The security gaps need resolution before achieving large-scale integrated smart automation.

Various Expert Opinions

The future of technology is always hard to predict, especially when reviewing complex issues such as smart technologies. Job losses in manufacturing and other areas due to smart technologies have been a main area of research over the last few years. The studies in this area can also provide insights into experts' opinions regarding adopting these technologies. Autor et al. (2003) argue that smart technologies with formal, repeatable rules can replace manual tasks. The costs associated with technology for replacing these tasks should reduce over time. Occupations that perform many routine tasks might have lower development costs for multiple tasks and thus higher computer adoption, all else equal (Bessen, 2015). Specific tasks in manufacturing may be more impacted by I 4.0. Some research on job loss is presented dramatically as a tale about automation and permanent unemployment. Although based on the feasibility and adoption of technologies, the actual impact may be far more nuanced and limited than some doomsday forecasts suggest.

A study by Michaels and Graetz (2015) reviews the impact of technology in manufacturing, agriculture, and utilities across 17 countries. They found that industrial robots significantly contributed to labor productivity and aggregate growth, increasing wages and total factor productivity (2015). One of the examples in the study found that robots reduced the hours of lower-skilled workers—but did not decrease the total hours worked by humans and boosted wages (2015). The study concluded that automation might affect humans' work, but it is hard to see that it leads to a world without work. For example, ATM adoption was supposed to replace human labor but increased the number of banks (Bessen, 2015). As a result, the number of bank tellers also rose between 2000 and 2010 (Bessen, 2015).

Technology investment has also grown more slowly since 2002 than in any other postwar period. That is the opposite of what to expect in a rapidly automating world (Bessen, 2015). For example, the US's total spending on all robotics was just $11.3 billion in 2016, about one-sixth of US spending on pets (Bessen, 2015).

The job loss due to technology predicted by experts is currently all over the map (see figure 6 (Winnick, 2018). A review by MIT consolidated all of the studies and showed the difference in the number of jobs impacted, see figure 7 (Winnick, 2018). The predictions made by several global experts in economics and technology are not even close to each other (Winick, 2018). The only meaningful conclusion derived from various studies is that the future of jobs and industries will change, but no conclusive information on how many jobs will be lost or gained to technological progress (Winick, 2018).

When	Where	Jobs Destroyed	Jobs Created	Predictor
2016	worldwide		900,000 to 1,500,000	Metra Martech
2018	US jobs	13,852,530*	3,078,340*	Forrester
2020	worldwide		1,000,000-2,000,000	Metra Martech
2020	worldwide	1,800,000	2,300,000	Gartner
2020	sampling of 15 countries	7,100,000	2,000,000	World Economic Forum (WEF)
2021	worldwide		1,900,000-3,500,000	The International Federation of Robotics
2021	US jobs	9,108,900*		Forrester
2022	worldwide	1,000,000,000		Thomas Frey
2025	US jobs	24,186,240*	13,604,760*	Forrester
2025	US jobs	3,400,000		Science Alert
2027	US jobs	24,700,000	14,900,000	Forrester
2030	worldwide	2,000,000,000		Thomas Frey
2030	worldwide	400,000,000-800,000,000	555,000,000-890,000,000	McKinsey
2030	US jobs	58,164,320		PWC

When	Where	Jobs Destroyed	Jobs Created	Predictor
2035	US jobs	80,000,000		Bank of England
2035	UK jobs	15,000,000		Bank of England
No Date	US jobs	13,594,320*		OECD
No Date	UK jobs	13,700,000		IPPR

Figure 7. Consolidated view of automation job studies.

Note. From every study we could find on what automation will do to jobs, Winick, E, 2018. https://www.technologyreview.com/2018/01/25/146020/every-study-we-could-find-on-what-automation-will-do-to-jobs-in-one-chart/. Copyright 2018, MIT Technology Review.

It can be concluded that a better understanding of different factors related to I 4.0 adoption is needed. The emphasis should be on the pace of technology adoption that may lead to structural changes in the field.

Organizational Change and Readiness

Industry 4.0 will impact all of the company's facets, and a strong plan is needed to manage this organizational change. Several large-scale projects fail due to a lack of change management (Kotter, 2009). Change management consists of various aspects, including communication, technology, culture, behavior, and others. Companies establish their change management plans based on the current state. Change management is the process of successfully implementing organizational changes due to technology, processes, market, and other forces.

These change plans help the business develop a specific path based on its needs. Over the years, several models have been developed to manage organizational changes, such as Kotter's 8-step model, The Prosci ADKAR Model, Plan Do Check Act, and others. These models rely on developing a change model approach based on various factors.

The 'Readiness' for change is critical for successfully implementing changes (Kotter, 2011). The definition of Readiness is an individual or organization's cognitive state comprising beliefs, attitudes, and intentions toward the change effort (Holt et al.,2007b). It is a precursor to adoption, and when readiness exists, the organization's chances of successfully increasing the change increase (Holt et al., 2007b). Kotter (2009) suggests that failure to establish readiness leads to half of the unsuccessful change efforts. Thus, readiness is one of the most critical factors in initial support for change initiatives (Holt et al., 2007b). As the implementation of I 4.0 will be a sizeable organizational change for the companies, the readiness for this change needs to be understood.

Armenakis et al. (1993) proposed a model for creating readiness and proposed that readiness was a precursor of resistance and adoption behaviors. One of the main steps in the model is the readiness assessment. The assessment helps measure the organization's readiness before implementing the changes. It can also help the leaders, project managers, and other stakeholders identify the gaps related to capabilities. Then, appropriate action plans to address those gaps can increase the likelihood of successful implementation.

Readiness assessments use qualitative as well as quantitative tools. Although qualitative methods provide incredibly rich change-specific information, Quantitative methods are an appropriate supplement, offering unique advantages to managers, organizational development consultants, and researchers in specific settings (Armenakis et al., 1993). A quantitative assessment can help gather information quicker over a large and varying group of firms. Also, the assessment can be conducted with a pre-built reliable instrument. A quantitative assessment instrument can help understand a company or industry's readiness.

Industry 4.0 Roadmaps

A technology roadmap matches technology implementation goals with short- and long-term action items (Phaal et al., 2004). It supports generating a plan associated with technology adoption (Phaal et al., 2004). The frameworks proposed by roadmaps vary based on the technology and associated factors. Roadmaps can be instrumental in identifying steps required to implement a technology. Several technology roadmaps have been proposed for I 4.0 deployment as well. Qin (2016) points out that the proposed roadmaps for I 4.0 are unclear. Mittal et al. (2018) conducted a literature review of the roadmaps proposed by different researchers. They highlighted that it is essential to identify the roadmaps related to the evolution of manufacturing toward adopting I 4.0. Roadmaps, Frameworks, Maturity Models, and Assessments are interchangeable terms associated with I 4.0 models (Mittal et al., 2018). They identified only 15 relevant and robust papers due to the “new” nature of I 4.0. The research critically reviewed the 15 models, and the key findings were (Mittal et al.,2018):

- Roadmaps, assessments, models, and frameworks are used synonymously to provide steps for I 4.0 implementation.
- Individual researchers have different perspectives on understanding and dimensions.
- The studies focus on either roadmaps or assessments but lack the union of both roadmaps and assessments to provide a comprehensive analysis.
- The models, the factors, and other variables associated vary based on the research.
- There is no standard roadmap for I 4.0 deployment.

- The articles and reports have acknowledged using surveys or pilot studies to validate maturity models.

In conclusion, although roadmaps are important in technology adoption, a standard roadmap for I 4.0 has not been defined. The methodology section provides the appropriate roadmap, framework, or assessment model.

Different Assessment models

The assessment of readiness before introducing change has been encouraged, and several instruments have been developed to fulfill that purpose (Holt et al.,2007b). These existing instruments appear to measure readiness from several perspectives: change process, change content, change context, and individual attributes (Holt et al.,2007b). Several I 4.0 readiness assessment tools have also been developed worldwide. The dimensions and data collection methods vary, but they all aim to understand the current state of industry readiness.

As readiness is an essential factor identified, the researchers have developed various quantitative assessment tools to measure the industry readiness for I 4.0. These tools help academia, as well as companies, establish baseline readiness levels. Rajnai and Kocsis (2018) share that currently, there is no standard and proven process for assessing I 4.0 readiness. The dimensions to measure readiness in instruments vary, but the goal is the same. Some of the most popular assessment tools are:

NIST - Smart Manufacturing Systems Readiness Level (SMSRL) Tool (NIST, 2018): The SMSRL developed by the National Institute of Standards and Technology focuses on evaluating the readiness or maturity of a factory related to I 4.0. In the SMSRL, activities are subdivided into their applicability at the various control levels, including Enterprise, Site, Area, Process Cell, Unit, Equipment Module, and Control Module. They measure dimensions such as

Management, Personnel, Software, Output Data Format, KPIs, and KPI relationship. These 4 measurement categories are C1: Organizational Maturity, C2: IT Applications Maturity, C3: Performance Management Maturity, and C4: Information Connectivity Maturity. Each measurement category has its calculation method to quantify the maturity level and derive customized factory improvement plans. The tool also walks the user through the necessary assessment steps. It provides 2 different modes, a complete assessment, and a scope selection mode. Users can thoroughly investigate their current practices in the complete assessment mode. On the other hand, the scope selection mode provides a use-case-driven assessment including 1) Layout Design, 2) Capacity Analysis, 3) Material Flow Analysis, 4) Equipment Design, and 5) Comprehensive Review.

The assessment tool uses the Factory Design and Improvement (FDI) activity model. It is good from the perspective of changes a certain factory or facility may have to implement. However, it lacks the strategy, employees, and other elements a company may need to evaluate. There is also little usage of this tool in the existing I 4.0 readiness studies.

PricewaterhouseCoopers (PwC) Industry 4.0 assessment tool (PwC, 2017): This assessment tool aims to assess the company's readiness and be the future planning anchor for I 4.0. The tool has seven dimensions, Digital business models, Digitization of product and service offerings, Digitization and integration value chains, data and analytics, Agile IT architecture, Compliance, Security, Legal and tax, and Organization employees and Digital culture. Each dimension has four readiness levels: digital novice, vertical integrator, horizontal collaborator, and digital champion. It also has a dimension of compliance, security, legal, and tax.   This is also an open-access tool available for companies. PwC has used it to survey over 2000 companies across 26 countries.

The tool uses the business services model of PwC. It is focused on financial and business processes compared to manufacturing processes. It is not dedicated to manufacturing companies and measures the overall readiness for digital transformation. It is not a dedicated I 4.0 assessment tool.

The University of Warwick Industry 4.0 Readiness Assessment (University of Warwick, 2018): This tool provides a simple and intuitive way for companies to measure their readiness and develop plans for I 4.0. It looks beyond technology to consider 6 core dimensions with 37 sub-dimensions. The core 6 measurement dimensions are products and services, manufacturing and operations, strategy and organization, supply chain, business model, and legal considerations. Each dimension has four levels beginner, intermediate, experienced, and expert. These are assigned based on the detailed breakdown of the sub-dimensions. Along with strategy and technology dimensions, it also includes a legal dimension. This survey has been used to measure readiness for 53 companies across 22 countries.

The tool is designed to cover over 37 separate dimensions of I 4.0 adoption. Consequently, collecting the data via this instrument can be time-consuming and complex. The number of dimensions and questions make it challenging to perform analysis.

IMPULS – VDMA assessment (VDMA, 2017): VDMA (Association of plant and mechanical engineering) built an assessment tool for measuring German companies' readiness towards Industry 4.0. It is a web-based tool that measures six dimensions, strategy and organization, smart factory, smart operations, smart-products, data-driven services, and employees. Each dimension also contains additional information with other detailed measurements. There are six levels of readiness, from levels 0 to 5. Level 0 is considered an outsider, where the company does not apply digitalization. Level one is the beginner level; these companies have started their digital journey and adopted I 4.0 principles. The additional levels have a higher level of readiness with level 2 intermediate, level 3 experienced, level 4 expert, and level 5 top performer, where I 4.0 is embedded into all of the company's processes. The original survey measured the readiness of 200 manufacturing companies in Germany.

The survey is designed to measure the core components of I 4.0 adoption. Since its inception, it has been employed by multiple researchers around the world. It is open access and is dedicated to the manufacturing industry. The online tool provides a summary along with areas for improvement. The limitation is the lack of reliability and validity statistics, and too many dimensions require a large sample to measure differences in subcategories.

Researchers have identified industry readiness as an area of research; several studies have been conducted worldwide using these or other assessment tools. Maisiri and Van Dyk (2019) conducted a study in 2019 using the modified VDMA tool to measure the readiness of the South African industry. Sheen and Yang (2018) conducted a readiness survey for South Korean industries deploying the Korea Productivity Center model. In addition, VDMA has been used across several European countries to measure I 4.0 readiness (VDMA, 2017). Although the variations and applications of assessment models differ, it has been a significant area of research in different countries.

Chapter Summary

Technology Management is a set of disciplines that allow organizations to manage their technological fundamentals to create a competitive advantage. The manufacturing industry has gained significant efficiencies from integrating technologies since the 1700s. I 4.0 is a new field that applies several emerging technologies to manufacturing. Various researchers, countries, policymakers, academia, and other stakeholders consider it the next frontier of manufacturing process improvement. PwC (2018) predicts that adopting new manufacturing technologies can accelerate the global economy's productivity by between 0.8 and 1.4 percent of the global GDP annually.

I 4.0 is about inter-connected processes leading to digitization and significant productivity improvements. In I 4.0, the equipment and processes transfer information through different layers for autonomous decision-making. Machines are capable of monitoring their processes, and they can also make adjustments based on performance. The machines and the product carry and transfer information. The systems are highly flexible and adaptable for custom, or on-demand interconnected manufacturing.

IoT, Cloud Computing, CPS, and Big data analytics technologies work together to enable I 4.0. IoT aims to solve communication issues among all objects and systems in a factory. CPS provides the interaction between physical and information systems, while cloud services provide easy access to information and services. Lastly, Big data and analytics are critical enablers to advanced applications of I 4.0 since the system's intelligence depends on the large amount of data accumulated (big data) and the capacity to analyze with advanced techniques (analytics).

Although researchers agree with the importance of I 4.0, there is disagreement on its adoption and impact. There is not even a standard definition of I 4.0. Several studies have been conducted on the impact on jobs due to new technologies. The number of jobs ranges from millions to a few thousand. It is a clear indication that this field needs a better understanding. It also leads to several questions and concerns associated with I 4.0's adoption. The actual pace of technology adoption and implementation may be much faster or slower (Arntz et al., 2016). Challenges associated with machine capabilities include unstructured tasks, visual capabilities, reactions to failures, manipulation, and others. Challenges are associated with standardizing equipment, protocols, costs, rules, and regulations in this field.

As the adoption needs to be understood, industry readiness can help gauge the future pace of adoption. Several researchers highlighted that readiness is an essential factor impacting organizational change. In I 4.0, Roadmaps, Frameworks, Assessment models, and other terms are used interchangeably to measure and address readiness. Various frameworks and instruments have already been developed to measure I 4.0 readiness. This study used one of the existing frameworks and instruments to measure the readiness of US manufacturing for I 4.0.

CHAPTER 3

METHODOLOGY

The research measured the readiness of US manufacturing for Industry 4.0. This chapter provides information on the research design and the methodology.

Research Design

Research methods have developed over time. Based on the need, research can be conducted via quantitative, qualitative, or a combination of both methodologies. The nature of the data, research questions, and hypothesis drive the choice of the method itself (Creswell & Creswell, 2018). In addition, the choice depends on whether the intent is to specify the type of information collected before the study or to allow it to emerge through analysis (Creswell & Creswell, 2018). All 3 research methods are considered valid for conducting research.

After evaluating the 3 research methodologies, the quantitative method was selected as the most appropriate. It is routinely depicted as an approach to conducting research that applies a natural science, particularly a positivist approach to social phenomena (Bryman, 1984). Its roots are in the Postpositivist view based on experimental design and the Constructivist view of ethnographic design and observation (Creswell & Creswell, 2018). The underlying tenant of quantitative research is a philosophical belief that our world is relatively stable and uniform, such that it can be measured and understood and make broad generalizations about it (Mertler, 2020). Quantitative methods aim to expand knowledge through the exploration of numerical patterns. The goal is to describe situations, establish relationships, and sometimes explain the relationship (Mertler, 2020).

Various quantitative studies are surveys, experimentation, correlation, ex-post-facto, and others. Descriptive studies are on one end of quantitative studies, where the variables are observed and not controlled. On the other end are experimental studies where the study design establishes a relationship. Correlational studies are closer to descriptive studies that aim to establish relationships between variables through statistics. In a quasi-experimental study, on the other end, the researcher establishes relationships through naturally established groups. Quantitative methods use deductive reasoning. Through analysis of data using statistics, the hypothesis is proven false or not false. These methods rely on learning about a population based on the sample. Quantitative methods tend to be (Creswell & Creswell, 2018):

- Pre-determined, the researcher has already decided on the specific variable (s) that are supposed to be measured.
- Instrument-based, numerical data such as performance, attitude, etc., is collected via a survey or another tool. Information gathering happens from Structured interviews, historical data, and records.
- The statistical study analyzes the information, and through hypothesis testing, conclusions are made based on statistical interpretation.

Different quantitative analyses are descriptive research, correlational research, quasi-experiments, and experimental research. Descriptive research focuses on describing the current status of a variable. The purpose of a descriptive study is to describe and interpret the current status of individuals, settings, conditions, or events (Mertler, 2020). Thus, it seeks to describe the current status of an identified variable. The main purpose of this methodology is to describe or provide information regarding a phenomenon. Two of the most common research designs in this are observational and survey research. The nature of this study is to "describe" the industry readiness, and it is descriptive. Hence, the quantitative methodology is appropriate.

Survey Research's central purpose is to describe a group or population (Mertler, 2020). In survey research, an instrument collects the data from a sample. Mertens (2005) describes the descriptive survey as an approach to describe the characteristic of a sample at one point. By studying the sample, survey research delivers a quantitative or numeric description of a population's trends, attitudes, or opinions (Creswell & Creswell, 2018). Then, the data can be statistically analyzed to measure people, companies, and other entities' behaviors and attitudes.

Creswell (2005) states, “Survey researchers often correlate variables, but their focus is directed more toward learning about a population and less on relating variables or predicting outcomes as is the focus in correlational research.” The correlational research design assesses the relationship between the variables identified. Therefore, it is the best approach for meeting the requirements of the second research question. Lappe (2000) states that descriptive correlational research describes the relationship among variables rather than inferring cause and effect relationships. Descriptive correlational studies describe how one variable is related to another in situations where the researcher has no control over the independent variables. The correlational research in this study compared the numerical data between independent and dependent variables. A relationship indicates one variable’s ability to influence one or more variables. Of the designs associated with the quantitative methodology, the correlational design is most appropriate for the second part of the study since the intent is to determine the relationship between the two sets of variables.

Donalek and Soldwisch (2004) stated, "Quantitative research is deductive. It presupposes a constant, stable, external reality that is measurable and follows discernible rules of science. Its purpose is to measure some portion of that fixed reality". It tends to be less in-depth but allows for broader research through fixed options or observations. As the studies are not too in-depth, they can be generalized easily (Bryman, 1984). This study was quantitative and descriptive. The industry readiness data was collected via an online questionnaire.

Demographic Factors

The adoption of I 4.0 depends on several demographic factors as well. However, two key components highlighted in different studies are the Company Size and the Type of manufacturing.

The adoption of I 4.0 requires extensive resources and investment in new technologies. Mittal et al. (2018) highlight that financial resource availability is important for adopting I 4.0. Businesses will rely heavily on access to investments and the return on investment for the new technologies. Large and small businesses may have unique circumstances related to access to capital and requirements for return on investment. It is important to understand if there is a difference based on the company size. There is no universal method for measuring the company's size (Rajnai & Kocsis, 2018). The company size for this research was categorized based on the number of employees. The North American Industry Classification System (NAICS) tracks the US industry statistics with the census bureau (US Census, 2022). Table 2 shows company size by the number of employees for manufacturing codes 31-33 (US Census, 2022). This research used the 5 categories from NAICS for the company size.

Another highlighted factor is the type of manufacturing within the industry (Kusiak, 2017; Mittal et al., 2018). Based on the type of manufacturing, it may be more or less prone to I 4.0

adoption. Groover (1996b) recommends manufacturing processes in 5 categories. The types of manufacturing categories are (Groover, 1996b).

- Repetitive: Production of a similar product or component with minimum changeovers.
- Discrete: Production of various products or components with frequent changeovers.
- Batch: Production from customer demand or material availability, with long runs and extended changeovers.
- Process: Production is continuous, running 24/7.
- Job shop: Production of small custom products in small batches based on customer orders.

Table 2

US Census Manufacturing Classification by number of employees.

Enterprise Industry Classification (NAICS)	NAICS Description	Enterprise Employment Size	Number of Enterprises
31-33	Manufacturing	1: Total	248,835
31-33	Manufacturing	2: <500 employees	245,963
31-33	Manufacturing	3: 500-999 employees	1,359
31-33	Manufacturing	4: 1,000-4,999 employees	1,192
31-33	Manufacturing	5: 5000+ employees	32

Research Questions (RQs)

Quantitative research measures a phenomenon or tests relationships between Independent and Dependent variables (Creswell & Creswell, 2018). The first research question is descriptive, and the goal is to understand a phenomenon. This study aimed to measure US manufacturers' current readiness level for I 4.0 adoption.

RQ1: What is US companies' readiness level for Industry 4.0 adoption?

The second part of this study is correlational. It tested the hypothesis that readiness varies by the company size or type of manufacturing.

RQ2: Does the level of Readiness vary based on the company demographic factors of Company Size or Type of manufacturing?

The first RQ measured the overall readiness. The second RQ determined if there is a statistically significant difference in readiness based on company size or type of manufacturing.

Hypothesis 1

Ho_1: There is no statistically significant difference in readiness for Industry 4.0 between company sizes.

Ha_1: There is a statistically significant difference in readiness for Industry 4.0 between company sizes.

Hypothesis 2

Ho_2: There is no statistically significant difference in readiness for Industry 4.0 among the type of manufacturing process.

Ha_2: There is a statistically significant difference in readiness for Industry 4.0 among the type of manufacturing processes.

RQ3: What is the level of concern related to various Industry 4.0 technology challenges?

The third RQ measures the level of concern related to cyber security, costs, technology capability, system integration, and employee skills.

RQ4: What are the main obstacles to the adoption of Industry 4.0?

RQ5: What are the factors driving the adoption of Industry 4.0?

Questions 4 and 5 in the research are open-ended. These questions provided qualitative information on obstacles and driving factors related adoption of I 4.0.

Population and Sample

Population: Creswell and Creswell (2018) clarified that a target population is a group of individuals or organizations demonstrating the common relevant identifiable characteristic for the research. The target population for this study was the business leaders of United States (US) manufacturing companies. Business leaders are vital in supporting change management (Kotter, 2011). Leaders provide the vision, direction, and resources for organizational change (2011). Effective leadership is the key to successful change (Hao & Yazdanifard, 2015). Manufacturing Leaders can help gain an understanding of their company's I 4.0 readiness. The target population for this study was the decision-makers of US manufacturing companies. US Census for manufacturing companies identifies 248,835 companies (United States Census Bureau, 2022). The total population size is 248,835 companies in the United States (2022). The population included business leaders such as Directors of manufacturing, Plant Managers, or functional leaders of these manufacturing companies. The target population provided information on company readiness for strategy and technical factors.

Sample: The sample is a subset of the population. Sampling techniques can be a probability as well as nonprobability. Ideally, the goal of a researcher should be to draw a random sample, but in many cases, it is not possible (Creswell and Creswell, 2018). Alternatively, the non-probabilistic technique can be applied for sampling (2018). The non-probabilistic technique of convenience sampling was used for this research. Morse and Niehaus (2009) suggest that irrespective of the methodology employed, sampling methods should maximize efficiency and validity and be consistent with the aims and assumptions of using either method.

The non-probability sampling selected for a study depends on the study's type, nature, and purpose (Creswell & Clark, 2007c). It involves identifying and selecting individuals or groups that are especially knowledgeable about or experienced with a phenomenon of interest (2007c). Gurung (2015) stated that convenience sampling is acceptable in a new study such as I 4.0. It also targets a population meeting a criterion, such as ease of access, who is keen to participate in the study (Creswell & Clark, 2007c). Etikan et al. (2016) points out that this technique is beneficial due to the importance of availability and willingness to participate. This research utilized convenience sampling. This technique ensured that the data collected was from relevant subjects in the field.

One of the disadvantages of convenience sampling is that it is more prone to bias (Etikan et al., 2016). The results may not be generalized to the population. Various techniques can be applied to reduce the bias. By making the sample representative of the population, the bias in convenience sampling can reduce (Etikan et al., 2016). The goal should be to reduce the number of survey non-respondents by distributing the survey to as many people as possible (Maisiri & Van Dyk, 2018). For this research, convenience sampling bias was addressed by ensuring that the sample was selected from different platforms.

The research methodology, survey, and related materials were approved on April 3, 2023 by Indiana State University’s Internal Review Board (IRB) to protect the rights and welfare of human subjects. See Appendix B for IRB approval. The data was collected using IRB-approved materials. The participants were selected through the author’s LinkedIn network, the Society of Manufacturing Engineers (SME), and the Kansas City section of the American Society of Quality (ASQ). The author invited members of the personal LinkedIn network who met the survey study criteria. The survey was also posted on the SME website. The Kansas City section of ASQ shared the invitation with its members. Demographic questions related to I 4.0 knowledge and role in the company were added to identify relevant sample. Users with no knowledge of I 4.0 and individual contributors were excluded from the final analysis.

Industry 4.0 Readiness Framework

Industry 4.0 is a new industry topic. Rajnai and Kocsis (2018) share that currently, there is no standard and proven process for assessing its readiness. Different researchers have proposed several assessment instruments. In 2015, the Impuls Foundation of Verband Deutscher Maschinen- und Anlagenbau (VDMA) developed an assessment tool for measuring Germany's manufacturing readiness for I 4.0. It is an online assessment tool that anyone can use. The self-check uses the same six dimensions of I 4.0 and compares this self-assessment (actual profile) with the profile of leading I 4.0 companies (benchmark profile) and the profile of the target vision (target profile) (VDMA, 2015). It shows companies where they are in good shape and where they need to optimize (2015). An I 4.0 readiness study was published in 2015 by VDMA.

Framework Dimensions

The six dimensions form the basis for measuring the I 4.0 readiness of the companies (VDMA, 2015) are shown in Figure 6. It provides an overview of the structure of the Readiness Model. The inner circle shows the six basic dimensions. The outer circle shows the fields associated with each of the six dimensions. A total of 18 fields are measured using the appropriate indicators.

The six dimensions of the framework are shown in figure 8 (VDMA, 2015):

- Strategy and organization: I 4.0 is about improving existing products or processes. It creates the opportunity for new business models. It is a strategic initiative and must be considered accordingly by a company. Implementation status of strategy, operationalization, and strategy review through a system of indicators can help gauge the company's level of readiness.

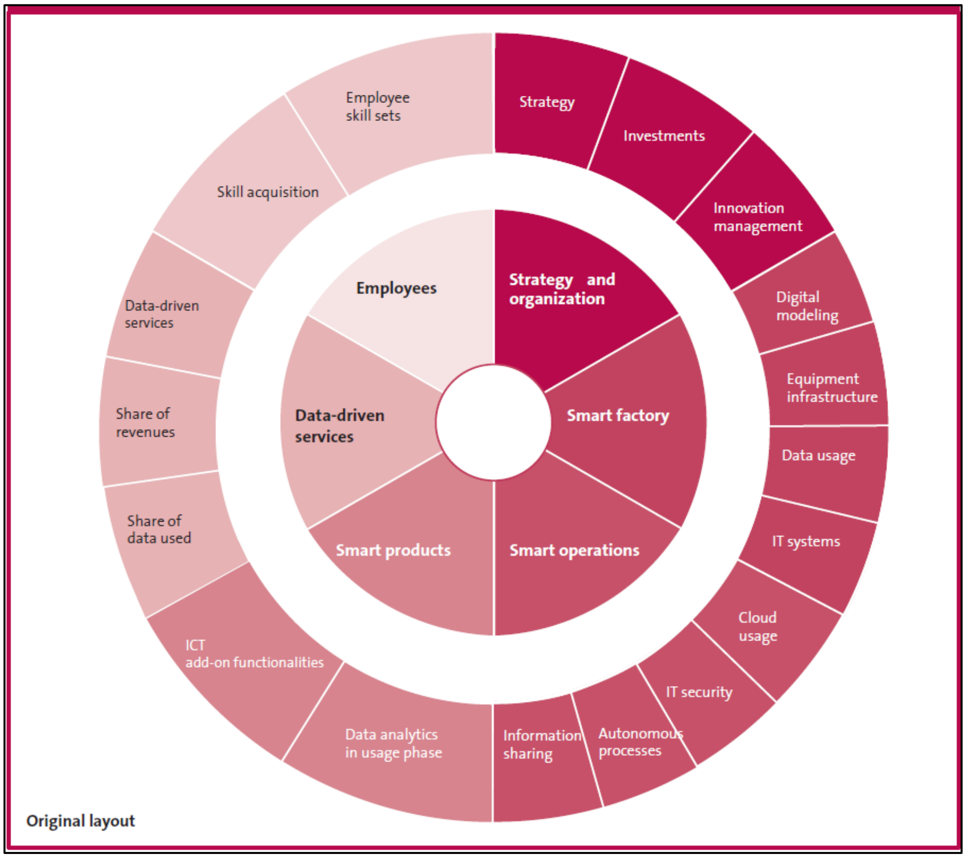

Figure 8. VDMA Readiness Assessment Model.

Note: From Industry 4.0 Readiness.

http://Industry40.vdma.org/documents/4214230/5356229/Industry%204.0%20Readiness%20Study%20English.pdf. Copyright 2015. Implus

- Smart factory: It is the concept of an intelligent, interconnected factory in which the production systems communicate directly with the overlying IT systems. A key feature is the placement of comprehensive sensor technology (IoT) throughout the factory. It denotes a highly productive manufacturing environment of connected and intelligent machines and materials where waste, defects, and downtime are minimized (Diederik, 2014). Process efficiency is optimized in this environment through machinery and equipment automation and self-optimization. Smart factory is a dynamic integrated cyber-physical-human manufacturing system in which the physical resources are implemented as smart things that communicate with each other and human resources via IoT infrastructure (Zheng et al., 2018).

- Smart Operations: The hallmark I 4.0 is the enterprise-wide and cross-enterprise integration of the physical and virtual worlds (horizontal and vertical integration). The advent of digitization and the data from production and logistics makes it possible to introduce new forms and approaches to planning and management. Integrating technical requirements in production and production planning is necessary for smart operations.
- Smart product refers to products with different types of sensors embedded in them. During their life cycles, they can communicate with the environment and collect, store, and transfer data (Schmidt, 2015). For example, during different process steps, in manufacturing, they can communicate information about location, time, state, steps, and others. Customers can facilitate information around consumption patterns (Gilchrist, 2016).
- Data-driven services: It is the combination of the physical and digital worlds to create new services for customers. It focuses on after-sales and services business by evaluating and analyzing collected data and enterprise-wide integration. The products must be equipped with physical IT to send, receive, or process the information, which can create digitized services in the usage phase of the products.
- Employees: One of the goals of I 4.0 is to simplify tasks. Employees will be affected by the changes in the digital workplace. Employees play a key role in change processes,

which has already been validated in multiple studies (PwC, 2014). The working environment will be altered, leading to the requirement for new skills and qualifications. The companies must prepare the employees for these changes through appropriate training and continuing education.

Readiness Levels

The overall readiness level is calculated based on the survey results. The company's readiness is explained by six levels shown in figure 9 and measured from levels 0 to 5 (VDMA, 2015):

- Level 0: Outsider. The company does not meet any of the requirements for I 4.0. It is also designated to companies indicating that Industry 4.0 is either unknown or irrelevant.
- Level 1: Beginner. The company is involved in I 4.0 through pilot initiatives in a single area. However, IT systems support a few production processes, and the existing equipment infrastructure only partially satisfies the future.
- Level 2: Intermediate. The company incorporates I 4.0 into its strategic orientation. It is developing a strategy to implement I 4.0 and the appropriate indicators to measure the implementation status. Investments are being made in a few areas. Some of the production data is collected automatically with limited use.
- Level 3: Experienced. The company has formulated an I 4.0 strategy. It is making related investments in multiple areas and promoting I 4.0 through department-oriented innovation management. The IT systems in production are linked through interfaces and support the production processes, with data in key areas automatically collected.

- Level 4: Expert. The company is using an I 4.0 strategy and monitoring it with appropriate indicators. Investments are being made in nearly all areas, and the process is supported by interdepartmental innovation management.
- Level 5: Top performer. The company has already implemented its I 4.0 strategy and regularly monitors the implementation status of other projects. Investments throughout the company support this. In addition, the company has established enterprise-wide innovation management.

Readiness level	***Description***	***Criteria***
Level 0: Outsider	• Either no requirement is met, or Industry 4.0 is unknown and irrelevant.	0
Level 1: Beginner	• Pilot initiatives in Industry 4.0, investments in single area. • Infrastructure partially meets future requirements. • Skills are found in few areas.	0 < Points ≤ 50
Level 2: Intermediate	• Incorporating Industry 4.0 into the company strategy. • Investments in noticeable number of areas. • Partial automation in collection of data. • Skills available in some areas to pursue Industry 4.0.	50 < Points ≤ 90
Level 3: Experienced	• Strategy formulated. • Investments in significant number of areas. • Infrastructure may be upgradable. • Security in place for the information technology systems.	90 < Points ≤ 120
Level 4: Expert	• Industry 4.0 strategy in use. • Investment achieved in almost the entire organisation • Large amounts of data collected automatically and used for optimisation purposes. • Availability of add-on information technology functionality in the products.	120 < Points ≤ 145
Level 5: Top performer	• Industry 4.0 strategy implemented and monitored for progress. • Industry 4.0 investments in the entire company • Infrastructure satisfies all Industry 4.0 requirements.	145 < Points ≤ 160

Figure 9. Readiness Level Description.

Note. Industry 4.0 readiness for South African Industry, Maisiri & Van Dyk, 2019. (http://dx.doi.org/10.7166/30-3-2231). Copyright 2019, SAIIE.

Support for VDMA Framework

VDMA framework has been evaluated and used by several other researchers to measure I 4.0 readiness since its inception. " It is one of the remarkable works, titled 'Guideline Industry

4.0—Guiding principles for the implementation of Industry 4.0 in small and medium-sized businesses, presented by the VDMA (German Engineering Federation), proposes an 'Industry 4.0-toolbox' that should provide first guidance" (Rauch et al., 2020). The survey is a good starting base for assessing one's company implementing I 4.0 technologies and concepts (Rauch et al., 2020). Maisiri and Van Dyk (2019) also evaluated various readiness surveys for the I 4.0 readiness of South African companies. They compared assessment models proposed by Judit, the Readiness Index by Blanchet, Rinn, von Thaden, and de Thieulloy, the Readiness model by Geissbauer, Vedso, and Schrauf, along with Forrester's four digital maturity dimensions of culture, technology, organization, and insights. Based on the comparison, they concluded that the measurement dimensions in the IMPULS tool are most appropriate for measuring the readiness of SMEs in I 4.0. Axmann and Harmonko (2020) compared the VDMA, PwC, and Uni-Warwick readiness assessments and concluded that the VDMA tool is superior in the number of dimensions and categories relevant to I 4.0 readiness. Basl and Kopp (2017) used the IMPULS tool to measure the readiness of Czech companies. They also concluded that the I 4.0 readiness assessment by VDMA is a well-grounded tool (2017). VDMA framework has been used and suggested by researchers to perform exploratory I 4.0 readiness assessments. Based on the prevalent use and researcher recommendations, this study used the VDMA framework to measure I 4.0 readiness.

Survey Instrument

A modified version of the VDMA survey was employed to support the research goals. Questions were changed to a 5-point Likert scale to accommodate statistical analysis. Also, the geographical questions were modified to align with the research goals. The survey contains 3 main sections:

Demographic Questions: The questions in this section were used to capture the independent variables associated with the research goals. The questions related to the subject's role, knowledge of I 4.0 technologies, size of the company, and manufacturing process type.

Readiness Questions: The questions in this section focused on different elements of I 4.0 readiness. The elements with the definitions are:

- Strategy: I 4.0 is a major organizational change for any company. A strategy for its adoption is needed to deploy it successfully.
- Employees: Employees' direct working environment will be altered by I 4.0, requiring them to acquire new skills and qualifications. Employee I 4.0 skills range from data and system security, technology, maintenance and troubleshooting, and systems thinking to data management.
- Vertical and Horizontal integration: Vertical integration links various systems and hardware, such as sensors, actuators, controllers, etc. Horizontal integration links processes such as manufacturing, quality, procurement, etc.
- Smart factory: A smart factory is a production environment where the systems largely organize themselves with minimal human intervention. The smart factory relies on cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things (IoT).
- Smart products: Smart products are a key feature of I 4.0. Physical products are equipped with ICT components (sensors, RFID, communications interface, etc.) to collect data on their environment and status.

Concerns: The questions in this section focused on measuring the level of concern related to different areas of I 4.0. These areas are cyber security, equipment costs, technology capability, integration, and employee skills.

Obstacles: The survey also contained an open-ended question for the obstacles related to I 4.0 adoption. This can help identify the areas for improvement.

Driving Factors: It is also important to understand the motivating factors driving the company towards I 4.0. The survey also contained an open-ended question for the driving factors.

See Appendix A for the questionnaire.

Survey Reliability and Validity

The experts have reviewed the VDMA framework and instrument for face and content validity. Face validity is the degree to which a measure appears to be related to a specific issue (Taherdoost, 2016). It is established when an individual (and or researcher) who is an expert on the research subject reviewing the questionnaire (instrument) concludes that it measures the characteristic or trait of interest (Bolarinwa, 2015). Content validity refers to how a measure thoroughly and appropriately assesses the skills or characteristics it is intended to measure (Taherdoost, 2016). Content validity is established through a literature review and then follow-ups by expert judges or panels (Bolarinwa, 2015). A combination of face and content validity can enhance the overall validity of the instrument (Weiner & Craighead, 2010). Research on technical or criterion validity has shown significant positive correspondence between face validity and test accuracy (Holden & Jackson, 1979). Test items with face validity are more accurate or valid than those possessing no face validity (Weiner & Craighead, 2010). The relationship between face and technical validity is significant and stable (2010). Both the face and content validity were incorporated into the study.

An iterative process was used for the validation of the survey instrument. Initially, modifications were made to the instrument by the researcher based on the literature review. These changes were tested for face validity and followed by appropriate modifications. A panel of industry experts reviewed the instrument for face and content validity. The panel tested the survey for content as well as face validity. The final survey was created based on the expert panel's feedback. The expert panel's members were:

- Quality: Dr Gary Lee, Director of Quality at Amprod Holdings.
- Quality: Dr Larry Brown, Professor, Defense Acquisition University.
- Manufacturing: Dr Kay Morgan, Assistant Professor, Mississippi State University.
- Manufacturing: Sudipto Mukherjee: Senior Director of Global operations, Johnson and Johnson. Mike Malik: Director of Manufacturing, Farmer Brothers.
- Information Technology: Nelly Shibaeva: Vice President Enterprise Systems, Technic FMC.

ISU's IRB (Internal Review Board) process was utilized to protect the rights and welfare of survey participants in the study. The researcher completed IRB training and obtained exempt approval from the IRB committee before collecting data.

Instrument Pretest

A survey pretest with a small test group of 30 users from the study population was conducted. Internal Consistency is the most important form of instrument reliability (Creswell & Creswell, 2018). The Cronbach alpha was employed to measure the instrument's internal consistency. Creswell and Creswell (2018) recommend a value of .7 to .9 for a reliable survey instrument. In the case of this survey, Cronbach's alpha value is .835, as shown in table 3.

Table 3

Survey Reliability Statistic Cronbach Alpha.

Cronbach's Alpha	N of Items
.835	6

Limitations

The study relied on an online survey to collect the data. Online survey limitations are associated with response bias and the ability to verify the accuracy of participants' responses (Pedersen & Nielsen, 2014). They also yield lower response rates than mailed surveys, influencing research results (Pedersen & Nielsen, 2014). Also, the researcher could not verify the survey responses with independent data due to a lack of in-person accessibility. As convenience sampling was applied to this study, the generalizability of this study is limited. The study's results are limited to leaders participating in the research. Also, it is important to establish the reliability and validity of an existing instrument (Creswell & Creswell, 2018). Reliability is the consistency of survey questions, and validity is the extent to which the survey measures the topic (2018). Although the VDMA survey has been used and recommended in several studies, no validity or reliability statistics have been published for the survey instrument. The modified survey was tested for validity and reliability.

Chapter Summary

Research is conducted via quantitative, qualitative, or a combination of both methodologies. Quantitative methods aim to expand knowledge through the exploration of numerical patterns. The quantitative study aimed to describe situations, establish relationships, and sometimes attempt to explain the relationship (Mertler, 2020). This measured US manufacturing's readiness for I 4.0 adoption. By studying the sample, survey research offers a quantitative or numeric description of a population's trends, attitudes, or opinions (Creswell & Creswell, 2018). The study was quantitative and descriptive. The industry readiness data was collected via an online questionnaire.

The study's target population was decision-makers of US manufacturing companies. The population was the leaders of manufacturing organizations. It included all manufacturing processes, including discrete, batch, processing, and industries. The target population can provide information on different aspects of readiness for the company from strategy and technical factors. The non-probabilistic technique of convenience sampling was used for this research. Creswell & Clark (2007c) suggest that sampling methods should maximize efficiency and validity and be consistent with the aims and assumptions inherent in using either method. Gurung (2019) stated that convenience sampling is acceptable in a new study area. For the research, convenience sampling bias was addressed by distributing the survey via different platforms.

Rajnai and Kocsis (2018) share that currently, there is no standard and proven process for assessing I 4.0 readiness. VDMA instrument has been used and suggested by researchers to perform exploratory I 4.0 readiness assessments. Due to its usage in research, the VDMA survey instrument was chosen for this study. The VDMA instrument was modified to fit the research goals. The readiness was explained by six levels, from 0 to 5.

The modified survey was tested for reliability and validity. Data was collected via Qualtrics online survey tool. The participants were selected through LinkedIn, SME, and the Kansas City section of ASQ.

CHAPTER 4

ANALYSIS AND RESULTS

This chapter provides the statistical analysis of the data collected and the interpretation to answer the research questions.

Survey Data

The data was collected using the online Qualtrics survey platform. Convenience sampling was applied to ensure the data was collected from the target population. Data was collected via multiple sources to reduce bias. The online questionnaire was emailed to the researcher's LinkedIn network. The invitation included plant managers, manufacturing directors, manufacturing functional leaders, vice presidents of manufacturing organizations, and other manufacturing leaders. The questionnaire was shared with the Indiana State University's technology management students. American Society of Quality, Kansas City section, also shared the questionnaire with its members. In addition, the survey was posted on the Society of Manufacturing Engineering's (SME) blog SME Connect. Demographic questions related to the roles and knowledge of I 4.0 were used to filter the responses not in the scope of the research.

A total of 426 survey responses were received. 66 incomplete surveys were discarded. 26 surveys were removed because of duplication. 14 surveys were removed due to repeated or the same responses across all categories. 124 survey takers identified themselves as individual contributors, and 10 responses were from non-manufacturing users; those were also removed. Finally, 14 users identified themselves with no knowledge of I 4.0, and their responses were also removed. The remaining 172 responses were used for the research analysis.

Descriptive Statistics

The Statistical Package for Social Sciences (SPSS), version 29, was used to analyze the collected quantitative data. Microsoft Excel 2021 was used for the qualitative data. The survey required the respondents to complete demographic information for independent variables. Table 4 shows the demographic statistics from the sample.

Table 4

Sample Demographic Data.

Manufacturing Role			Company Size		
A manufacturing functional leader.	87	43%	500 – 999 employees	93	46%
Plant Manager or leader for a single manufacturing site.	65	32%	1- 499 employees	72	36%
Manufacturing leader with a multi-site role.	43	21%	1000 – 4999 employees	27	13%
Other Manufacturing leader	7	3%	5000 + employees	10	5%
Knowledge of I 4.0			**Manufacturing Process**		
Proficient	86	43%	Batch	87	43%
Beginner	45	22%	Discrete	50	25%
Advanced	32	16%	Process	29	14%
Novice	32	16%	Repetitive	28	14%
Expert	7	3%	Job Shop	8	4%

Summary statistics are:

- Manufacturing Role: 87, 43% of the participants were manufacturing functional leaders, 65, 32% were plant managers for a single site, 43, 21% were manufacturing leaders for multiple sites, and 7, 3% were other manufacturing leaders.

- Company sizes: 93, 46% of the respondents were from companies with 500-999 employees, 72, 36% with 1-499 employees, 27, 13% with 1000 – 4999 employees, and 10, 5% with more than 5000 employees.
- Knowledge of I 4.0: 86, 43% of the respondents identified themselves as proficient, 45, 22% as beginner, 32, 16% as novice, 32, 16% as advanced, and 7, 3% as expert.
- Manufacturing process: 87, 43% of respondents selected
- Batch manufacturing, 50, 25% selected Discrete, 29, 14% selected Process, 28, 14% selected Repetitive, and 8, 4% of the respondents were from Job Shops.

Hypothesis Testing

The average readiness score across the 6 dimensions was used to measure readiness. The lowest possible score was 0, and the highest was 5. Table 5 lists the readiness levels and associated descriptions.

Table 5

Readiness Scores, Level, and Description.

Readiness Score	Readiness level	Description
0-1	Outsider	No adoption strategy and training plans. Systems and Processes are not integrated. No plans for Smart Products.
1-2	Beginner	Pilot initiatives, and investments in a single area. Infrastructure partially meets future requirements. Some plans to develop employee skills and smart products.
2-3	Intermediate	Investments in a noticeable number of areas, Partial automation in data collection, informal training plans, and smart products are being developed.
3-4	Experienced	Implementation Strategy formulated. Infrastructure may be upgradable, some

		training plans and testing of Smart products.
4-5	Expert	Strategy in use, data is being collected automatically, employees are being trained, and multiple smart products are being tested.
5	Top performer	Strategy is implemented, data is collected and adjusted automatically, employees are trained, and smart products are embedded in the processes.

Research Question 1(RQ1): What is US manufacturing companies' current Industry 4.0 readiness level?

Descriptive statistics for the average readiness score were used to answer the research question. The average readiness score in Table 6 was 3.011 or 60%.

Table 6

Average Readiness Score.

	N	Mean	Score
Average Readiness Score	172	3.011	60%

The readiness score was measured across the 6 dimensions of the framework and is shown in table 7.

Table 7

Average Readiness Score by Category.

Category	N	Mean	Score
Vertical Integration	172	3.314	66%
Smart Factory	172	3.279	66%
Horizontal Integration	172	3.267	65%
Strategy	172	2.947	59%
Employees	172	2.738	55%
Smart Products	172	2.523	50%

The score was highest in Vertical Integration at 3.314 and lowest in Smart Products at 2.523.

A paired samples t-test was employed to determine if there was a statistical difference in the elements of the Readiness Framework. All framework elements had a p-value lower than .05, as shown in table 8, except for Horizontal and Vertical Integration, Horizontal Integration and Smart Factory, and Vertical Integration and Smart Factory.

Table 8

Paired samples t-test for Readiness elements.

Pair	Factors	t	2-sided p
Pair 1	Strategy - Employees	2.643	.009
Pair 2	Strategy - Horizontal integration	-3.459	<.001
Pair 3	Strategy - Vertical Integration	-4.039	<.001
Pair 4	Strategy - Smart factory	-3.814	<.001
Pair 5	Strategy - Smart products	4.641	<.001
Pair 6	Employees - Horizontal integration	-4.958	<.001
Pair 7	Employees - Vertical Integration	-6.345	<.001
Pair 8	Employees - Smart factory	-6.214	<.001
Pair 9	Employees - Smart products	2.540	.012
Pair 10	Horizontal Integration - Vertical Integration	-.565	.573
Pair 11	Horizontal Integration - Smart factory	-.127	.899
Pair 12	Horizontal integration - Smart products	7.194	<.001
Pair 13	Vertical Integration - Smart factory	.405	.686
Pair 14	Vertical Integration - Smart products	7.902	<.001
Pair 15	Smart factory - Smart products	7.389	<.001

There is no statistical difference in the average readiness score of the 3 elements, Horizontal Integration, Vertical Integration, and Smart Factory. Hence, those 3 elements were combined into one category, System Integration. New descriptive statistics were generated for the readiness elements, as shown in table 9.

Paired samples t-test was conducted for 4 elem0ents. The p-value for average readiness levels was lower than .05 for all, as shown in table 10. Hence, they were all statistically different.

Table 9

Average Readiness Score by combined elements.

Readiness Element	N	Mean	% Score
Strategy	172	2.947	59%
Employees	172	2.738	55%
System Integration	172	3.286	66%
Smart products	172	2.523	50%

Table 10

Paired samples t-test values for Readiness elements.

Pair	Factor	t	df	2-sided p
Pair 1	Strategy - Employees	2.643	171	.009
Pair 2	Strategy - System Integration	-6.105	171	<.001
Pair 3	Strategy - Smart products	4.641	171	<.001
Pair 4	Employees - System Integration	-7.448	171	<.001
Pair 5	Employees - Smart products	2.540	171	.012
Pair 6	System Integration - Smart products	9.395	171	<.001

Research Question 2 (RQ2): Does readiness vary by Organization's Size and Type of Manufacturing?

<u>Hypothesis Testing 1</u>

Ho_1: There is no statistically significant difference in readiness for Industry 4.0 between company sizes.

Ha_1: There is a statistically significant difference in readiness for Industry 4.0 between company sizes.

First, descriptive statistics in table 11, were generated for readiness based on the company size. Companies with 1000-4999 employees have the highest readiness score as compared to companies with more than 5000 employees have the lowest score.

Table 11

Average Readiness Score by Company Size.

Company Size	N	Mean	% Score
1- 499 employees	62	2.940	59%
500 – 999 employees	78	3.068	61%
1000 – 4999 employees	24	3.201	64%
5000 + employees	8	2.437	49%
Sample Statistics	172	3.011	60%

ANOVA was utilized to test for statistical differences in average readiness scores between the 4 company size categories. The results are shown in table 12

Table 12

ANOVA test results by company size.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.063	3	1.354	2.112	.101
Within Groups	107.747	168	.641		
Total	111.810	171			

The significance of the p-value was higher than.05. Hence the null hypothesis could not be rejected. There is no statistical difference in the readiness level by company size. Since the number of samples related to companies larger than 5000 employees was only 8, the test was conducted without it. It resulted in a higher p-value of .363. Hence null hypothesis could not be rejected without companies with more than 5000 employees either.

In Table 11, the F statistic for the readiness score is 2.112. The observed significance level is 0.101, so the null hypothesis is not rejected, and the alternate is not tenable. The mean readiness score is the same for small and large enterprises. Therefore, based on the sample results, it can be concluded that there is no statistical difference in I 4.0 readiness among different sizes of companies.

Hypothesis Testing 2

Ho2: There is no statistically significant difference in readiness for Industry 4.0 among the type of manufacturing process.

Ha2: There is a statistically significant difference in readiness for Industry 4.0 among the type of manufacturing processes.

First, descriptive statistics shown in table 13 were generated for manufacturing processes.

Table 13

Descriptive Statistics by mfg. process.

Mfg. Process	N	Mean	% Score
Job Shop	8	2.208	44%
Batch	75	2.780	56%
Discrete	43	2.879	58%
Repetitive	25	3.640	73%
Process	21	3.666	73%
Total	172	3.011	60%

Companies with job shop processes have the lowest readiness score as compared to companies with process manufacturing with the highest readiness scores. ANOVA in table 14 was used to test for statistical differences in average readiness scores for 5 manufacturing process categories.

Table 14

ANOVA test results by mfg. process.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	28.814	4	7.204	14.495	<.001
Within Groups	82.996	167	.497		
Total	111.810	171			

The p-value in table 13 is lower than the hypothesized p-value of .05; hence, the null hypothesis must be rejected. There is a statistical difference between the readiness level by manufacturing process type. Tukey's B post hoc analysis in table 15 was conducted to identify the groups with the difference. Readiness for groups of Job, Batch and Discrete, and Repetitive & Process were different.

Table 15

Tukey's post hoc analysis for readiness score by mfg. process.

		Subset for alpha = 0.05		
Mfg. Process	N	1	2	3
Job Shop	8	2.208		
Batch	75		2.780	
Discrete	43		2.879	
Repetitive	25			3.640
Process	21			3.666

Based on these post hoc analysis results and the process definitions, the researcher combined Batch and Discrete and Repetitive & Discrete. ANOVA was re-run with the new categories and the descriptive statistics analysis in table 16.

Table 16

Average readiness score by combined mfg. process.

Mfg. Process Combined	N	Mean	% Score
Job Shop	8	2.208	44%
Batch & Discrete	118	2.816	56%
Process & Repetitive	46	3.652	73%
Total	172	3.011	60%

Job shop has the lowest readiness score of 2.208, Batch and Discrete have higher scores of 2.816, and Process and Repetitive have the highest score of 3.652.

The p-value is below .05 in table 17, and based on this null hypothesis can be rejected. Also, Tukey B's post hoc analysis in table 18 shows the difference between the three processes. In conclusion, the null hypothesis was rejected. Hence, there is a difference in the readiness level based on the manufacturing processes.

Table 17

ANOVA test results by combined mfg. process.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	28.534	2	14.267	28.953	<.001
Within Groups	83.277	169	.493		
Total	111.810	171			

Table 18

Tukey's post hoc analysis for readiness score by combined mfg. process.

		Subset for alpha = 0.05		
Combined Process Coded	N	1	2	3
Job Shop	8	2.208		
Batch & Discrete	118		2.816	
Process & Repetitive	46			3.652

RQ3: What is the concern related to various Industry 4.0 technology challenges?

This research question measured the concern level for cyber security, costs, technology capability, systems integration, and employee skills. These challenges have been highlighted in the literature review. The average score for each area was used. The lowest possible score was 0, and the highest was 5. Table 19 shows the average concern levels for the different areas.

Table 19

Average concern levels with technology challenges.

Areas of Concern	N	Mean
Cyber Security	172	3.802
Costs	172	3.703
Technology Capability	172	3.651
System Integration	172	3.540
Employee Skills	172	3.819

The highest concern is related to the employee's skills, and the lowest is related to integration. Scores for all areas were of high concern. The concern level all scores were high demographics.

Table 20

Average concern levels by company size.

Num of Employees	Average of Technology Capability	Average of System Integration	Average of Employee Skills	Average of Costs	Average of Cyber Security
1- 499 employees	3.652	3.583	3.902	3.708	3.875
1000 – 4999 employees	3.777	3.777	3.925	3.888	3.555
500 – 999 employees	3.720	3.526	3.655	3.720	3.860
5000 + employees	2.700	3.200	3.800	3.600	3.800
Sample Data	3.653	3.564	3.787	3.732	3.821

Table 21

Average concern levels by mfg. process.

Mfg. Process	Average of Technology Capability	Average of System Integration	Average of Employee Skills	Average of Costs	Average of Cyber Security
Batch & Discrete	3.627	3.445	3.788	3.700	3.759
Job Shop	2.875	3.625	3.875	3.625	3.125
Process & Repetitive	3.824	3.842	3.771	3.824	4.070
Sample Data	3.653	3.564	3.787	3.732	3.821

In conclusion, there is high concern related to all areas of I 4.0 technology challenges.

Research Question 4 (RQ4): What are the obstacles to adopting Industry 4.0?

The survey had open-ended question for this research question. 94 respondents did not provide feedback on the open-ended question. 78 responses were used to answer this question. The comments provided in the survey were analyzed. Common themes emerged from the comments. The comments were then categorized into these themes, as shown in table 22. Some responses had comments in more than one theme.

Table 22

Number of comments by different obstacles.

Obstacles	Num of Comments
Technology Barriers	24
Existing Systems	18
Leadership Knowledge / Skills	18
Employee Knowledge / Skills	16
Costs	12
Others	7

Research Question 5 (RQ5): What are the main factors driving the adoption of Industry 4.0?

The survey had open-ended questions for this research question. 91 respondents did not provide any feedback to the open-ended question, and 81 responses were used to answer this question. The qualitative data provided in the comments were analyzed, and the comments were categorized into the following themes, as shown in table 23.

Table 23

Number of comments by different driving factors.

Driving Factor	Num of Comments
Reliability	17
Integration	18
Efficiency	21
Market	17
Others	8

Summary results of hypothesis testing

Table 24

Summary of hypothesis testing

Test #	Null Hypothesis	Result
1	There's no difference in the average readiness by company size	Could not Reject
2	There's no difference in the average readiness by mfg. process	Rejected

Summary of Findings

- The overall Readiness for Industry 4.0 is 3.011 or 60%.
- The highest level of readiness is for Vertical Integration, 3.314, followed by Smart Factory, 3.279, and Horizontal Integration, 3.267. The lowest level of readiness is for Smart Products 2.523, followed by Employees, 2.738, and Strategy, 2.947.
- There is no statistical difference in the readiness level based on company sizes.
- There is a statistical difference in the readiness level based on the manufacturing process. The highest level of readiness for Process and Repetitive mfg., 3.652, followed by Batch & Discrete, 2.816, and the lowest for Job Shops, 2.208.
- There is no statistical difference in the readiness levels for Horizontal integration, vertical integration, and smart factory.
- There is a high level of concern in all the areas highlighted in the literature review related to the adoption of Industry 4.0

CHAPTER 5

CONCLUSIONS

This chapter reviews the purpose of the study and discusses various findings. The results and recommendations from the research are discussed.

Restatement of Purpose and Research Questions

This study conducted a readiness assessment for Industry 4.0 (I 4.0) of US manufacturing The data was collected via an online questionnaire. Readiness levels can help understand the pace of adoption. The research results benefit the stakeholders, including policymakers, manufacturing leaders, academia, companies, and others.

- Research Question 1(RQ1): What is US manufacturing companies' current Industry 4.0 readiness level? <u>The overall readiness level for the US was 3.011, or 60%.</u>
- Research Question 2 (RQ2): Does readiness vary by Organization's Size and Type of Manufacturing? <u>Organization Size did not affect readiness. The readiness varies by the Type of Manufacturing, highest for continuous processes and lowest for the job shops.</u>
- Research Question 3 (RQ3): What is the level of concern related to various Industry 4.0 technology challenges? <u>The concern for cyber security, costs, technology capability, system integration, and employee skill is high.</u>

- Research Question 4 (RQ4): What are the obstacles to adopting Industry 4.0? Technical Barriers and Skills for employees as well as executives are the biggest obstacles to Industry 4.0 adoption.
- Research Question 5 (RQ5): What are the main factors influencing the adoption of Industry 4.0? Cost and efficiency improvements are the main factors driving the adoption of I 4.0.

Industry 4.0 Readiness

The study's overall readiness score for the United States was 3.011 or 60%. Impuls recommends a 6-level readiness levels in table 25 that range from Outsider to Performer.

Table 25

Readiness Levels, Description, and Associated number of companies.

Readiness Score	Readiness level	Description	% of Companies
0-1	Outsider	No adoption strategy and training plans. Systems and Processes are not integrated. No plans for Smart Products.	2%, 4
1-2	Beginner	Pilot initiatives and investments in a single area. Infrastructure partially meets future requirements. Some plans to develop employee skills and smart products	11%, 23
2-3	Intermediate	Investments in a noticeable number of areas, Partial automation in the collection of data, informal training plans, and smart products are being developed	35%, 71
3-4	Experienced	Implementation Strategy formulated. Infrastructure may be upgradable, some training plans and testing of Smart products.	31%, 62
4-5	Expert	Strategy in use, data is being collected automatically, employees are being trained, and multiple smart products are being tested.	21%, 42
5	Top performer	Strategy is implemented, data is collected and adjusted automatically, employees are trained, and smart products are embedded in the processes.	0

Figure 10 shows the readiness levels for US manufacturing companies. Only 2% identified themselves as Outsiders. 11% consider them to be Beginners. 35% are intermediate, followed by 31% as Experienced and 21% as Expert. No company identified itself as Top Performer.

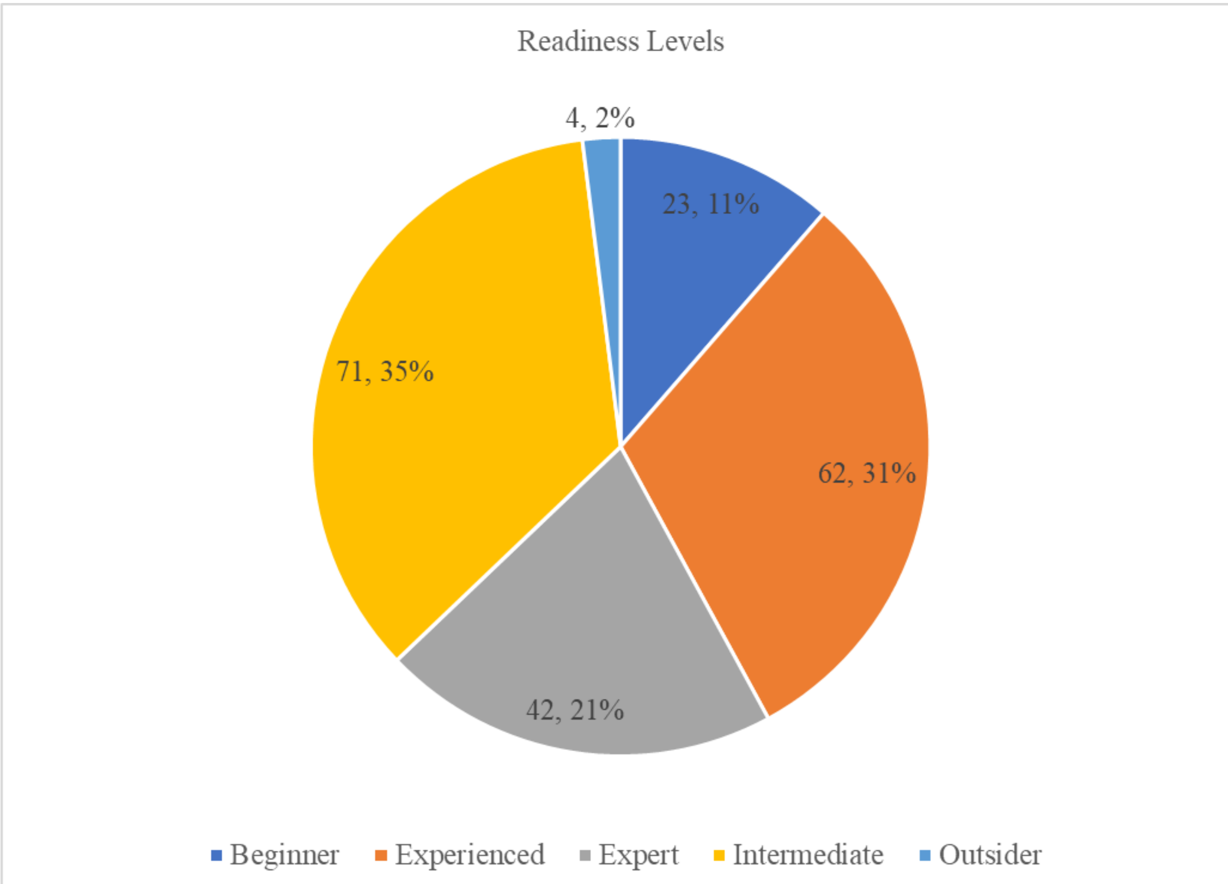

Figure 10. Readiness Levels Pie Chart.

Readiness levels for different elements are shown in Figure 11. System integration has the highest readiness score of 3.287 or 66%. It implies that the companies focus highest on the hardware and software elements of I 4.0 related to integration. High levels of activities are ongoing within different companies in interconnected factories through investment in IoT, equipment connectivity, information integration, infrastructure, and others.

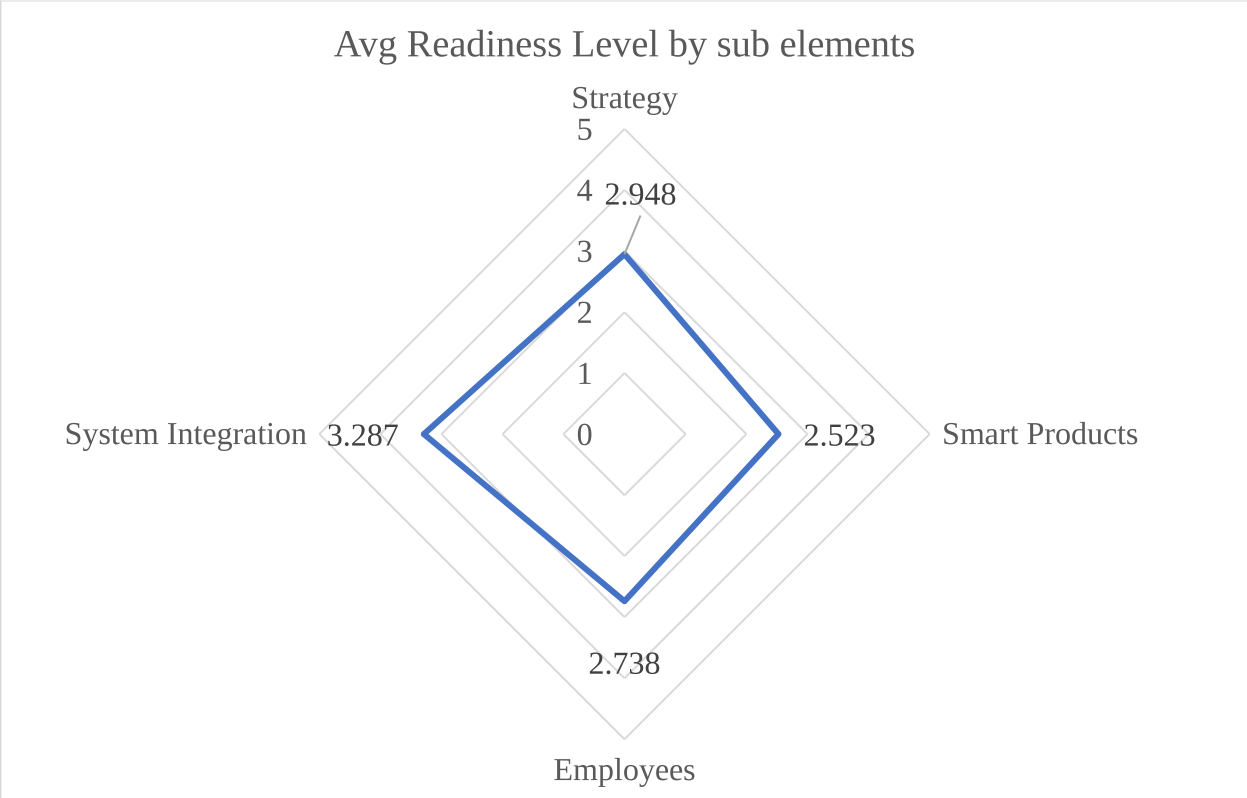

Figure 11. Readiness scores for the sub elements.

Strategy has the second-highest readiness score of 2.948 or 59%. Strategy is defined as the company's plans to adopt I 4.0. Strategy is one of the main factors for successful change adoption. Companies have some formal strategy and funding allocated to implementing I 4.0. The strategy score is lower than the systems. Companies are focused more on technology readiness than change management.

Employees has the third lowest readiness score of 2.738 or 55%. Employee readiness is defined as the skills associated with employees for I 4.0. As the adoption of I 4.0 increases, related employee skills are vital. Companies do not have clearly defined pathways to upskill the employees to adopt I 4.0

Smart products has the lowest readiness score of 2.523 or 50%. Smart Products contain sensors that provide information throughout the manufacturing and supply chain processes. The lowest scores imply that companies are investing in monitoring machines and processes, but smart products are not perceived as valuable as system integration.

Readiness level by the manufacturing process

Process and Repetitive manufacturing have the highest readiness score of 3.652 or 73% compared to other processes, as shown in figure 12. The industry currently is at the expert level. The industry seems to be further along than others in the readiness to adopt I 4.0. Process and Repetitive manufacturing have higher automation and technology integration levels than other processes. This makes this industry ideal for the adoption of I 4.0. Process and Repetitive manufacturing are generally made up of high-speed manufacturing processes such as food, chemical, automobiles, etc. These industries have some of the highest levels of automation and hence have a higher level of readiness for I 4.0 as well.

Batch and Discrete Manufacturing has the second highest readiness score, 2.81 or 56%. The industry is currently at the intermediate level. The readiness levels are also high across the elements. Preparedness for adoption seems to be ongoing. Batch and Discrete manufacturing has a lower level of process automation. Batch and Discrete manufacturing apply tools to make batches of similar products and have moderate to high levels of automation. Hence, they also have a moderate level of readiness for I 4.0.

Job shop has the lowest level of readiness of 2.208 or 44%. The industry is currently at the intermediate level. Only 8 responses were received for the manufacturing process, so the researcher cautions against the generalizability of these findings. However, job shops usually have high customization and lower automation levels, which may explain the lowest level of I 4.0 readiness. Job shops make custom products, which leads to a low level of automation in these processes and hence the lowest level of readiness for I 4.0.

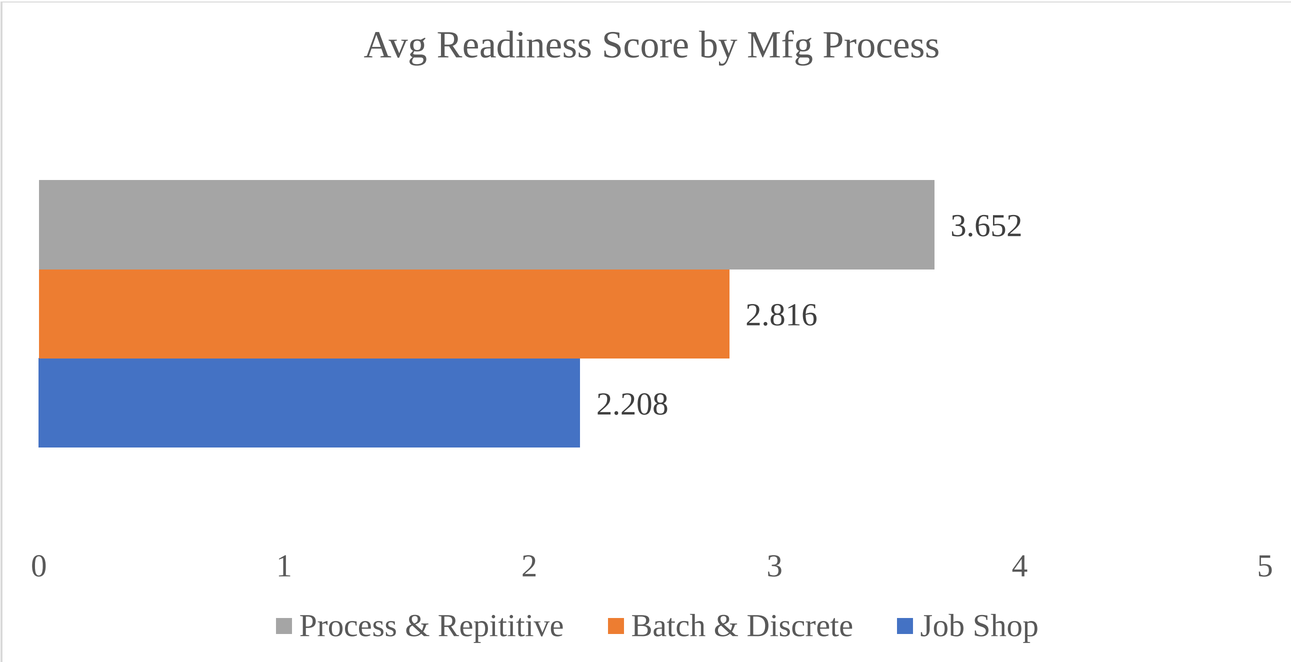

Figure 12. Readiness Score by Mfg. Process.

Based on the findings, all 3 process types have some activity ongoing to I 4.0 adoption. Each industry may have a different aspiration in terms of adoption. All technologies and features may not apply to every process type. The ideal readiness and adoption level will vary based on the industry need and should not be the same for all industries. Future research in the appropriate application of I 4.0 technology based on the process and the adoption level is recommended.

Concerns Related to Industry 4.0 Limitations

The biggest challenges are cyber security, costs, technology capability, systems integration, and employee skills. Figure 13 shows the average concern levels for the different areas. The highest concern is related to the employee's skills, and the lowest is related to integration. Scores for all areas were of high concern. No significant difference in any area was observed.

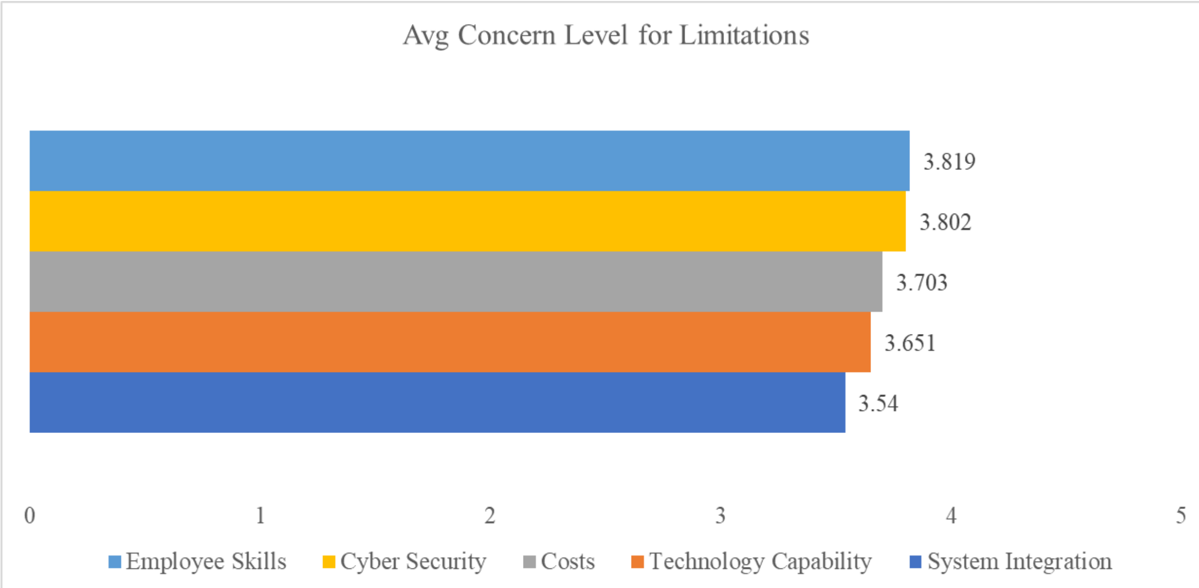

Figure 13. Average Concern Level for Limitations.

Driving Factors and Obstacles

<u>Driving Factors</u>

Qualitative data was gathered to understand the driving factors for adopting I 4.0. Efficiency was the biggest driving factor. Figure 14 shows the driving factors and the number of associated comments. As manufacturing is a highly cost-competitive industry, I 4.0 presents the next level of opportunities related to cost improvement. Improved reliability is also important, along with integration. Also, in many cases, the manufacturers are being pushed by competition and customers to adopt I 4.0. The themes are:

- Efficiency includes comments on cost savings, efficient processes, progress, flexibility, time savings, Return on Investment, process response, and others.
- Integration contains comments on linked processes and hardware, data conversion, connected equipment, tracking raw materials, process visibility, and others.

- Reliability consists of comments related to improved machine uptime, reduced maintenance costs, process visibility, and others.
- Market has comments on growth, global competition, customer demand, price, competitive advantage, etc.

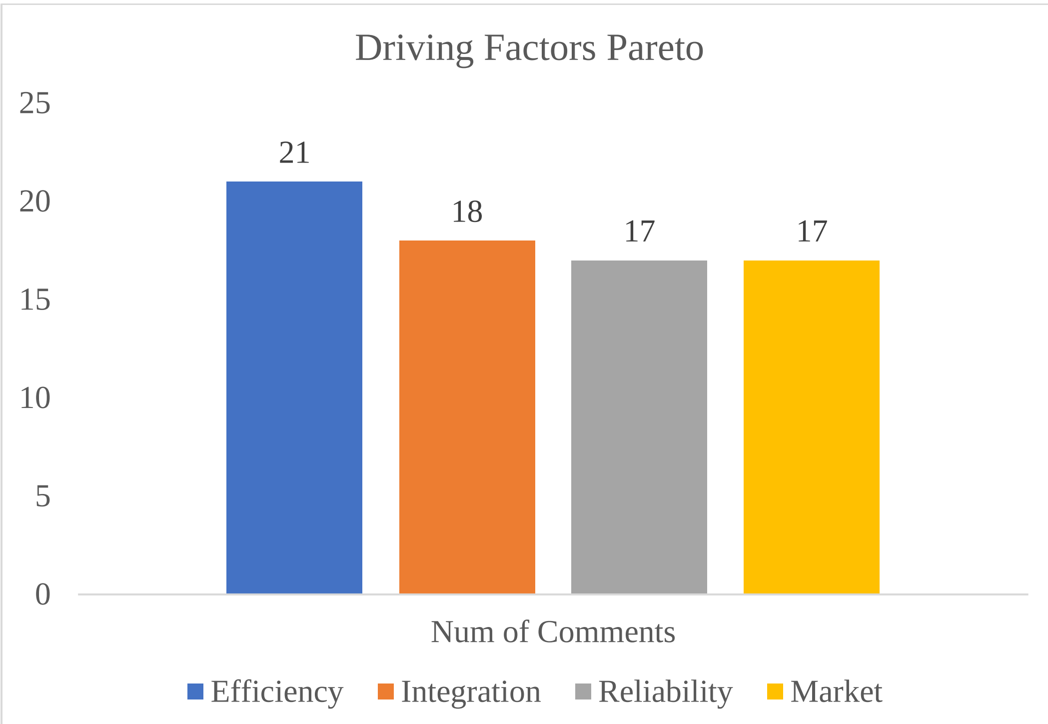

Figure 14. Driving Factors Pareto Diagram.

<u>Obstacles</u>

Qualitative data was also gathered to evaluate the concerns related to adopting I 4.0. In addition, qualitative information identified themes of the technology barriers, skills related to employees and executives, costs, and integration. Figure 15 shows the obstacles and the associated number of comments. The obstacles are:

- Technology Barriers includes comments related to hardware limitations, problems, software limitations, system flexibility, maintenance, changing technology, and others.

- Leadership Knowledge has comments on Executive and C suite knowledge and support of I 4.0.

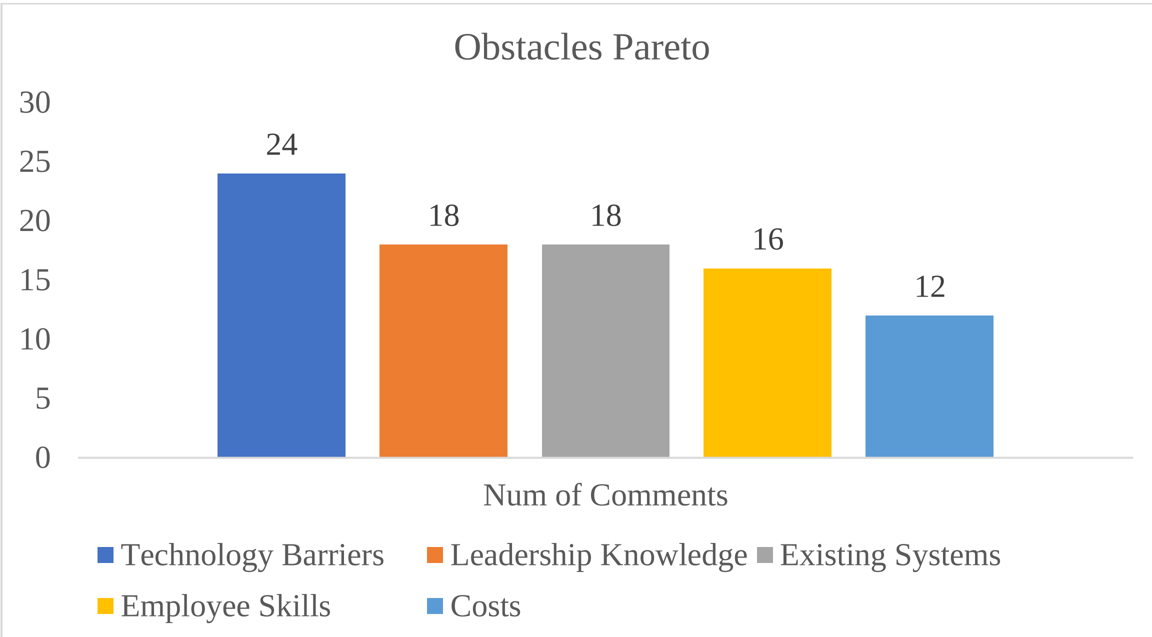

Figure 15. Number of comments associated with Obstacles.

- Existing Systems contains comments about existing machines, standardization, systems interaction, compatibility, scale of implementation, and others.
- Employee Knowledge Skills includes comments on training, skills, government programs for development, resistance, lack of technical skills, and others.
- Costs consists of comments related to new equipment, software, maintenance, and others.

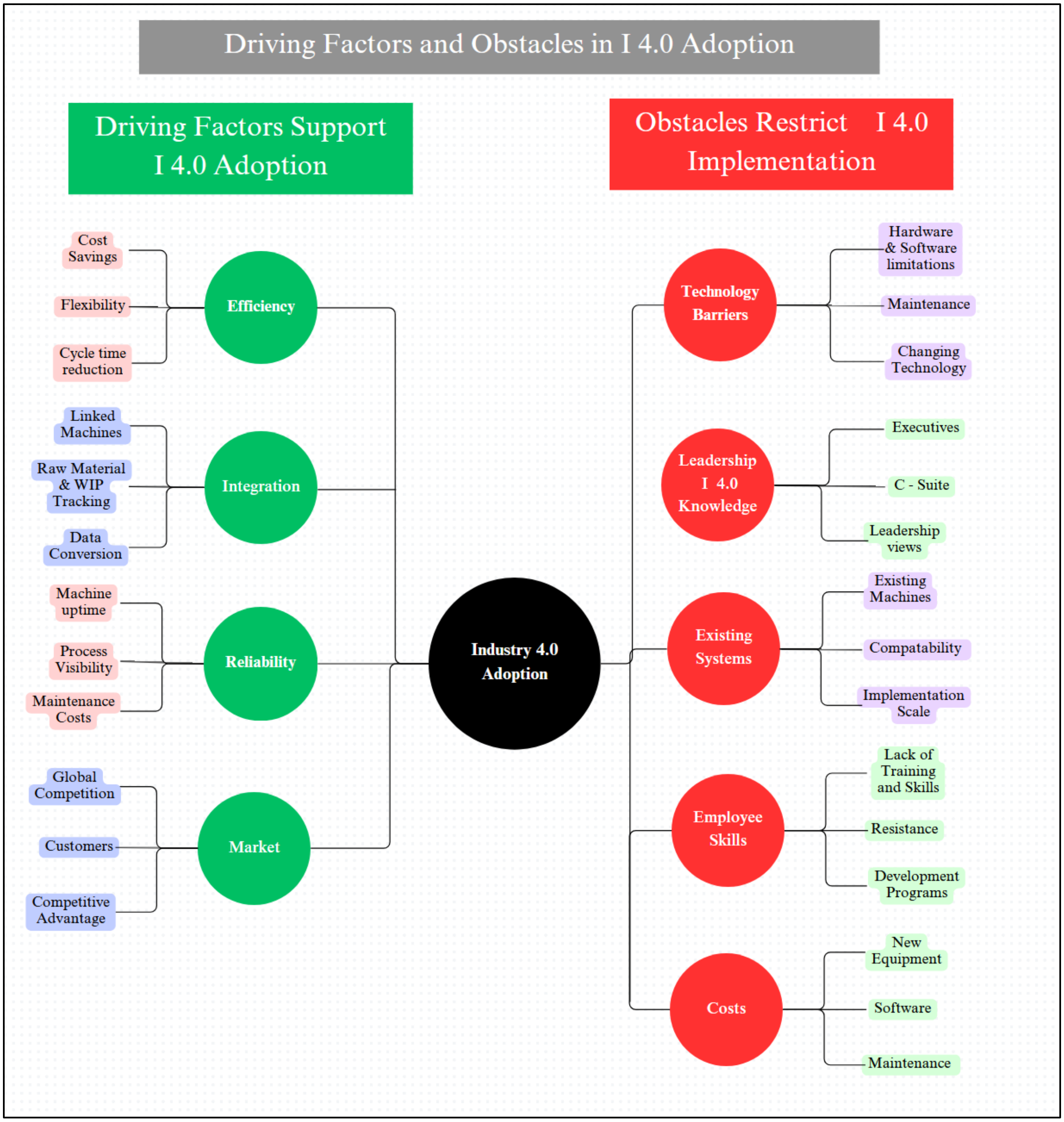

Figure 16. I 4.0 Driving Factors and Obstacles.

Force Field Analysis in figure 16 shows the competing forces related to adoption. The driving factors and obstacles work are the competing forces in this case. They work in opposite directions for I 4.0 adoption. The themes with specific areas for each side are shown.

Comparison with other Industry 4.0 Readiness studies

Multiple studies have been conducted across the world to measure I 4.0 readiness. This section compares the findings of those studies to this study.

VDMA Framework Studies

Germany: VDMA in 2015 conducted a readiness assessment for 602 German manufacturing companies. For manufacturing, 58% of the companies were Outsider, 31% Beginner, 8.6% Intermediate, 1.7% Experienced, 0.6% Expert, and none had reached Top Performer (VDMA, 2015). Efficiency and higher revenues were the driving factors for adoption. Also, mechanical engineering companies had a higher readiness score than manufacturing. Strategy and Employee Skills had the lowest level of readiness score.

South Africa: Readiness study for 36 South African manufacturing companies was conducted in 2019. It revealed that the overall readiness for the companies ranged between Outsider and Intermediate. 47 % Beginner and 8 % Intermediate (Maisiri & Van Dyk, 2019). Also, there was no significant difference in the readiness level of small, medium, and large enterprises (2019). Many organizations do not have an I 4.0 deployment strategy and lack the skills (2019).

Sweden: Swedish study on 602 companies on I 4.0 Readiness shows that for the small companies, 64.8% Outsider, 26% Beginner, 6.8% Intermediate, 1.6% Experienced, and 0.8% Expert (Machado et al., 2019). The Medium companies, 45.8% Outsider, while 40.9% Beginner, 11.5% Intermediate, and 1.7% Experienced (2019). 30.8% of the large manufacturing companies, 45.2% Beginner, 19.8% Intermediate, 3.9% Experienced, and 0.3% Expert (2019). There were no companies in Level 5 in any of the comparison groups. The study concluded that many companies focus mainly on technology but lack the strategy and other non-technical components (2019). Lack of I 4.0 knowledge is a major obstacle (2019).

Turkey: Turkish study completed in 2019 to measure the Readiness of I 4.0 for 3 manufacturing companies showed general optimism about adopting I 4.0. The companies lack strategy and employee skills for adoption (Temur et al., 2018). Although companies in Turkey are more followers than leaders in adoption, they believe it has significant benefits and will be transformational (2018).

Hungary: A readiness study for Hungarian companies showed that companies are on the journey to adopt I 4.0 despite the technical risks (Nick et al., 2019). They are in the process of integrating I 4.0 technologies (2019). 78% of the companies have begun collecting data from the processes, but process management using the data is lacking (2019).

Non-VDMA Framework Studies

European Union: EU Study was conducted to measure I 4.0 Readiness based on the factors of I 4.0 Infrastructure and Big Data Maturity. It identified Scandinavian countries as the leaders in I 4.0 Readiness (Castelo-Branco et al., 2019). Germany is also leading in infrastructure (2019). There are differences between Infrastructure and Big Data Maturity, with countries like Poland and Bulgaria being the laggards (2019). The study concluded that although there is wide variation in the readiness level among different countries due to wealth, industry, and other factors, overall, all countries are moving towards I 4.0 adoption (2019).

Brazil: Readiness study for I 4.0 concluded that High to medium-high-tech sectors have greater adoption. 61% of companies from the high-technology industries and 58% from the medium-high technology sectors have adopted at least one technology related to I 4.0 (CNI, 2016). In the medium technology industries, readiness is at 44% compared to 42% for low technology industries (2016). Reducing costs, increasing productivity, and improving processes are the main drivers for adoption (2016). The lack of skilled workers is the main barrier (2016).

Czech Republic: Readiness Study for 25 Czech companies from 2017 shows that 60% are trying to adopt I 4.0. There is a high awareness of I 4.0 among leaders but not among employees (Basl, 2017). 56% of the employees are unaware, and only 8% reported that I 4.0 is already part of the motivation of their employees (2017). Companies still lack an implementation strategy (2017).

Italy: Readiness study from 2021 for 77 Italian companies shows that only a few companies are investing in I 4.0 technologies. There is also a lack of I 4.0 knowledge and its benefits. 39% of respondents consider equipment and tools investment as one of the major obstacles, but 35% have difficulty acquiring and training internal skills (Tortora et al., 2021b). A skilled workforce is a concern (2021b).

Comparison Summary

<u>Similarities</u>

- I 4.0 is an area of focus for manufacturing companies. Despite the concerns related to cyber security, costs, and others, the implementation is ongoing in different countries.
- The adoption's main drivers are costs, efficiency, process improvement, competition, and others. These motivating factors are more important than concerns.
- The implementation focuses on technology adoption, and companies are investing in IoTs and integration efforts.
- The adoption requires change management as well as technical improvements. The companies lack strategy and change management plans for the adoption.

- Employee Skills are the main area of concern in almost every study. Although it is highlighted as a concern, there are few ongoing efforts to train the employees.
- Although Smart products are a key element of I 4.0 framework, there's little focus on it.

Differences

- Most of the studies have been performed based on company size. This study did not find a difference in readiness for company size.
- The industry's current level of technology penetration seems to impact I 4.0 adoption greatly.
- There was no significant difference in the readiness level for vertical integration, horizontal integration, and smart factory.
- Readiness in other studies has been lower as compared to this study. This may be a function of companies in the sample with mostly automated processes.
- Knowledge of the Executive / C suite has also been highlighted as an area of opportunity. There seems to be awareness at mid to senior-level management, but C Suite leaders must also understand the capabilities to support the implementation.

Despite technology limitations and other concerns, companies seem to be progressing toward I 4.0 adoption. Based on this, the focus for policymakers, industry leaders, and others should not only be on improving the concerns but also on supporting the driving factors. The benefits of I 4.0 for the companies outweigh some of the risks and concerns.

Industry 4.0 Adoption Framework

The adoption is a function of the Readiness level for the change, supported by the driving factors but slowed by the obstacles. The author proposes the adoption equation for any change effort in figure 17. To understand the adoption, readiness, driving factors, and obstacles should also be considered. This framework can also be applied to I 4.0 Adoption.

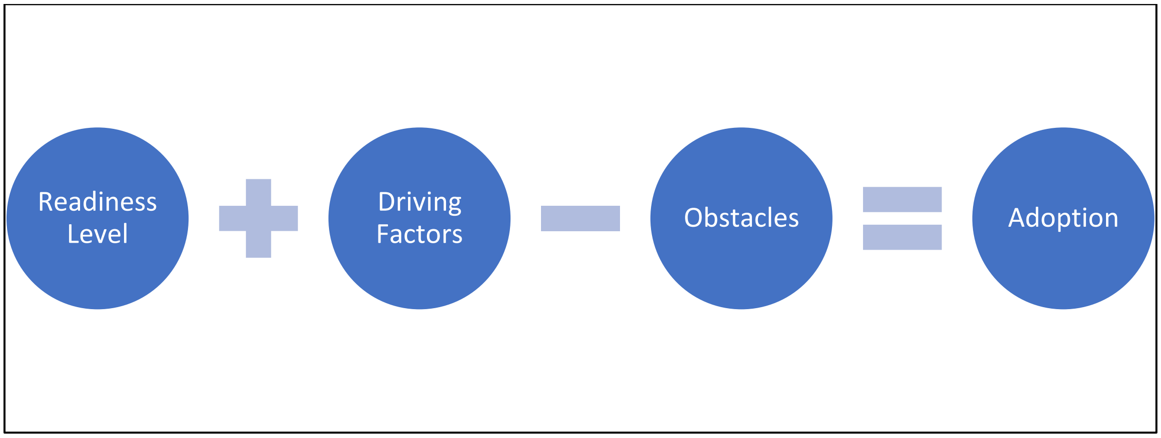

Figure 17. Adoption Equation.

I 4.0 Readiness Framework in figure 18 is based on factors from this research. Those are:

- Strategy and Change Management: There needs to be an additional focus on non-technology aspects. Large change efforts fail due to a lack of strategy and change management (Kotter, 2011). Nontechnical factors are as critical to the success of change initiatives as strong technology. Some of the recommended sub-elements are:
  - Detailed Strategy outlining the implementation.
  - Project Management for executing the strategy.
  - Metrics for tracking the execution plan.
  - Resources and Funding availability for implementation.
  - Transition plans to migrate existing processes.
- Leadership Knowledge: Executive leadership knowledge and support are vital to any effort's success. Before beginning the I 4.0 implementation, the leadership knowledge must be high. Some of the recommended sub-elements are:
  - Leadership existing knowledge.

  - Plans to train leadership in technologies.
  - Leadership support for implementation.

- <u>Existing Technology Adoption:</u> A company or Industry with a higher level of existing technology is likelier to adopt I 4.0 than the company size. If a company already has higher technology adoption, it may be easier and less costly to adopt new I 4.0 technologies compared to a company with low technology implementation. Some of the recommended sub-elements are:
  - Automation levels in the existing processes.
  - Type of Manufacturing processes.
  - Existing machine and system capabilities to adopt new technologies.
- <u>System Integration:</u> Although there's a significant effort ongoing in these areas. The various components of technology adoption, such as horizontal integration, IoT-specific areas, or system capabilities, should be continued to be measured. Some of the recommended sub-elements are:
  - Vertical integration of processes.
  - Horizontal integration of supply chain with suppliers.
  - Hardware connectivity of existing machines.
  - IoT adoption.
  - Enterprise Resource Planning system integration.
- <u>Employee Skills:</u> A company cannot succeed at I 4.0 implementation without the employee skills to use, support and maintain the equipment and the information. The area should focus on ongoing internal and external employee training.
  - Existing skills of employees.

- Training & Hiring plans based on I 4.0 needs.
- Educational institutions support the development of future skills.
- Public funding for development.

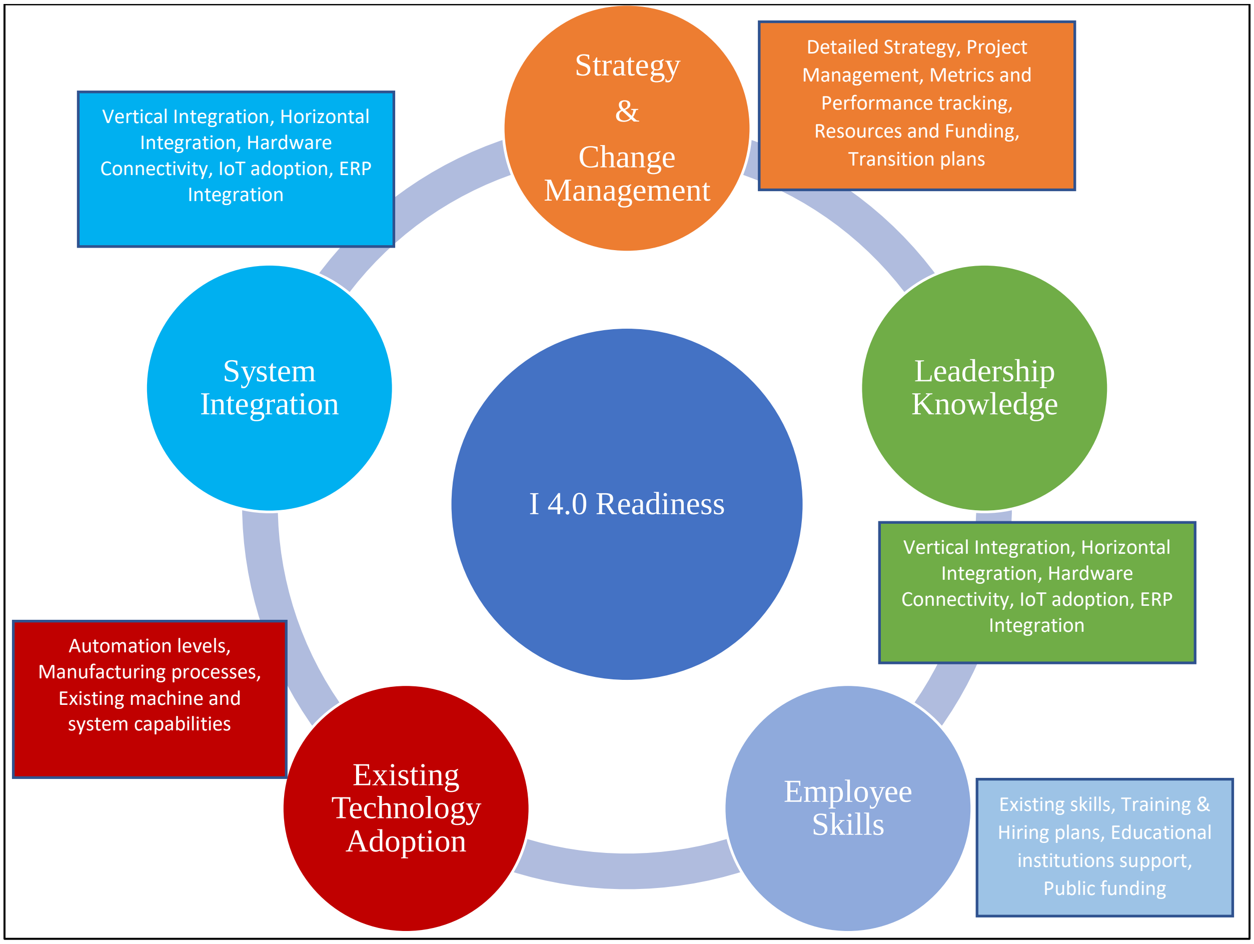

Figure 18. Proposed I 4.0 Readiness Framework with elements and sub-elements.

The stakeholders looking to increase the adoption should focus on all 3 elements of the adoption equation shown in figure 19.

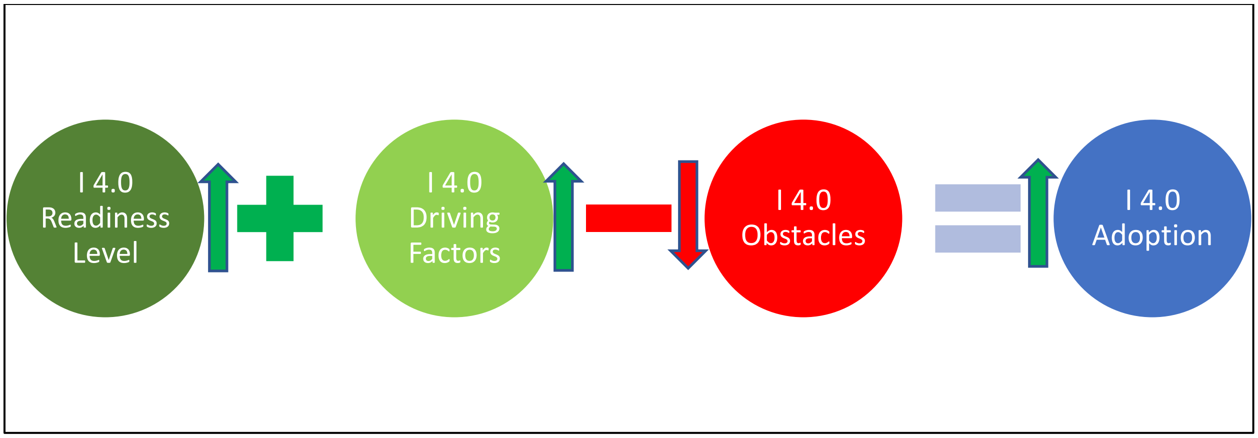

Figure 19. Proposed I 4.0 Adoption Equation.

The readiness level should be understood based on the framework and associated elements. The focus on driving factors can increase buy-in from leaders, even in industries that may be apprehensive. Reducing obstacles will also increase the adoption as the concerns are reduced. To increase adoption, readiness should increase, driving factors should be high, and obstacles should be low. Focusing on either factor of the equation will increase adoption.

Recommendations for VDMA Framework

The existing VDMA Industry 4.0 framework has the areas of Strategy, Employees, Smart Factory, Smart Operations, Smart Products, and Data-Driven Services. Data-Driven Services has also been excluded from other research due to lack of application. Suggested improvements to the Readiness framework for future research are:

- Combine Smart Factory and Smart Operations: This and other studies have pointed out that significant effort is ongoing in the companies related to I 4.0 technology adoption. No statistical difference in the categories was observed. These areas can be combined into one.
- Skills: Employee and Executive leadership skills have been highlighted as key areas of concern. The existing frameworks only measure employee skills. Additional focus should be on measuring the Executive level of I 4.0 knowledge.

- Smart Product does not appear to be an area of focus for most companies. This element should be further evaluated.

Recommendations to improve Industry 4.0 Readiness

Employee Skills have been listed as an area of opportunity in this and other research. Although it is a concern, businesses are not taking any initiatives to improve employee skills. Governments and policymakers will play a key role in helping workers adapt to the new environment. Policymakers will also have to partner with private institutions to help create training programs and job opportunities in the real world. As companies will be on the front lines of technology adoption, they will be familiar with the skills needed for the workforce. They can partner up with educational institutions to help train the workers. Policymakers can help subsidize the associated costs for businesses and educators. Education models need to change to the future needs of the workforce. The curriculum needs to be dynamic and technology-oriented. People must be open to working with machines and adopting these changes. They need to acquire new skills. Business Leaders and policymakers need to work together to train the workforce.

Focus on Benefits and Concerns: As pointed out in this study, manufacturing companies continue to adopt I 4.0 technologies despite several concerns. The concern areas include cyber security, equipment costs, technology capability, and others. All these areas are of high concern. These areas have been a focus of researchers and technology developers alike. The companies also see significant benefits from the adoption of I 4.0. The benefits are related to efficiency and cost improvements. The benefits seem to outweigh the associated risks. The companies seem to be progressing through adoption despite the risks. The challenges posed by concerns can be offset through more focus on showing benefits through full implementation. Business leaders and policymakers should focus more on the benefits than the limitations.

Existing Technology penetration seems to impact I 4.0 Readiness more than the organization's size. To improve I 4.0 Readiness, the needs for both industries with higher and lower technology implementation must be understood. The benefits of I 4.0 adoption must be understood and communicated in the case of low-tech industries such as job shops. The technologies need to be adopted for these processes as well. New technologies may also be needed. A custom readiness framework is needed based on the manufacturing process.

Recommendations for Future Research

Non-technical Readiness Levels: I 4.0 adoption is a social-technical issue. The companies are focused on advancing the technologies related to adoption. There is a gap in the US and other countries in the non-technology areas of readiness. This includes strategy, change management, long-term vision, execution plan, etc. Non-technical Readiness level factors are as or more important than technical readiness. Companies' hesitancy and lack of progress in these areas should be understood. The factors driving the lack of progress in these areas should be understood similarly to technical areas. It can help with improving readiness and adoption in the future.

Smart Products: They are defined as products with sensors that provide information related to the process through the supply chain. These products can provide information continually from initial manufacturing to the end customer. Despite the benefits offered by Smart products, they have the second lowest readiness level after employees. The companies are using I 4.0 primarily for monitoring internal processes and machine conditions. They do not perceive benefits from Smart Products to monitor the entire supply chain. Additional research should be conducted to understand the reasons for the lack of interest in Smart Products. Future frameworks should be modified to account for those findings.

Job Shops and other Low-tech industries: Only 8, 4%, of responses were received from the job shop in this study. The readiness score of 2.208, 44%, is the lowest in job shop manufacturing. Although a meaningful conclusion cannot be made from a small number of samples, other research has also pointed same concern. For future research, the needs of low-tech manufacturing industries must also be understood. In addition to understanding the need or driving factors, the modified readiness framework may be needed for these industries. The ideal readiness level and framework will vary depending on the industry's needs and processes.

Also, any research can benefit from additional samples and data. More studies should be done on other factors as well.

Final Conclusions

The study measured the I 4.0 Readiness for US manufacturing. The readiness score is 3.011 or 60%. The readiness is the highest in technology adoption and lowest for non-technology areas of Employee Skills and Strategy. The readiness is the highest for the repetitive & process mfg., followed by batch & discrete, and lowest for job shops. The size of the company has no impact on the readiness levels. The US and other countries are primarily focused on technology adoption but lack strong change management and employee development efforts. There are high concerns about technology. The adoption is ongoing in the US and other countries due to the benefits. Although the current focus is on technology improvements, the non-technical aspects and driving factors must also be nurtured.

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APPENDIX A - SURVEY INSTRUMENT

Demographic Questions

Select the role that's most appropriate for you:

- Manufacturing leader with a multi-site role.
- Plant Manager or leader for a single manufacturing site.
- A manufacturing functional leader.
- Individual contributor in manufacturing.
- Other manufacturing leader

What is your level of knowledge of Industry 4.0 (I 4.0) Technologies?

- None: Not familiar with I 4.0 technologies.
- Novice: Understand the concepts related to I 4.0 technologies.
- Beginner: Have informal experience with using I 4.0 technologies.
- Proficient: Have some formal experience with using I 4.0 technologies.
- Advanced: Led or Leading the implementation of I 4.0 technologies.
- Expert: Recognized as the subject matter expert in the field by peers.

Select the most appropriate company size based on the number of full-time people employed:

- 499 employees
- 500 – 999 employees
- 1000 – 4999 employees
- 5000 + employees

Select the most appropriate manufacturing processes for your company:

- Repetitive: Production of a similar product or component with minimum changeovers.
- Discrete: Production of various products or components with frequent changeovers.
- Batch: Production from customer demand or material availability, with long runs.
- Process: Production is continuous, running 24/7.
- Job shop: Production of small custom products in small batches.

Readiness Questions

Strategy: I 4.0 is a major organizational change for any company. A strategy for its adoption is needed to deploy it successfully.

Please answer the following questions related to the I 4.0 adoption strategy. 0 being the lowest, as no plans or metrics, and 5 being plans fully adopted or implemented.

What is your company's current level of Industry 4.0 adoption strategy?

0 1 2 3 4 5

What is your company's level of process indicators or metrics for tracking I 4.0 adoption?

0 1 2 3 4 5

Employees: Employees' direct working environment will be altered by Industry 4.0, requiring them to acquire new skills and qualifications. Employee Industry 4.0 skills range from data and system security, technology, maintenance and troubleshooting, and systems thinking to data management.

Please answer the following question related to Employee Skills. 0 being no plans to train employees and 5 being detailed plans to train the entire company workforce in Industry 4.0 skills.

What is your company's level of training plans for employee skills for Industry 4.0?

0 1 2 3 4 5

Horizontal integration:

Horizontal integration links processes such as manufacturing, quality, procurement, etc.

0 being no integration and communication and 5 being fully integrated data capture and automation.

What is your company's level of end-to-end integration between different manufacturing, quality, procurement/sourcing, and logistics functions?

0 1 2 3 4 5

Vertical Integration

Vertical integration links various systems and hardware, such as sensors, actuators, controllers, etc.

0 being no integration and communication and 5 being fully integrated data capture and automation.

What is your company's level of integration between different physical hardware and associated digital systems?

0 1 2 3 4 5

Smart factory: A smart factory is a production environment where the systems largely organize themselves with minimal human intervention. The smart factory relies on cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things (IoT).

<u>Please answer the following questions related to Smart Factory. 0 being no machine and process collection, 5 being fully automated collection between equipment and process.</u>

What is your company's level of data collection from manufacturing machines and related processes through IoT?

0 1 2 3 4 5

Smart products: Smart products are a key feature of Industry 4.0. Physical products are equipped with ICT components (sensors, RFID, communications interface, etc.) to collect data on their environment and status.

<u>Please answer the following question related to the Smart Products portfolio. 0 being no Smart products being considered, 5 being 100% of the company product portfolio are smart products.</u>

What is your company's current level of smart products?

0 1 2 3 4 5

Concerns: There are some concerns related to adopting I 4.0 Technologies in different areas. Please provide information on these issues, with 0 being no concern to 5 as the highest concern.

What is your level of concern related to Cyber Security of the Industry 4.0 equipment?

0 1 2 3 4 5

What is your level of concern related to the Cost associated with Industry 4.0 equipment?

0 1 2 3 4 5

What is your level of concern related to Industry 4.0 Equipment's Technology Capabilities?

0 1 2 3 4 5

What is your level of concern related to Industry 4.0 Equipment's System Integration issues?

0 1 2 3 4 5

What is your level of concern related to Employee Skills related to Industry 4.0 equipment?

0 1 2 3 4 5

Other Areas:

Based on your knowledge of Industry 4.0, what are the obstacles associated with the adoption of Industry 4.0.

Based on your knowledge of Industry 4.0, describe the main factors influencing the adoption of Industry 4.0.

APPENDIX B - IRB DOCUMENTS

Consent Form

US Manufacturing Readiness for Industry 4.0

Purpose: You are being invited to participate in a research study. This study aims to find out the readiness of US Manufacturing for Industry 4.0 / Smart adoption. The way you can help me answer this is by answering the questions in this anonymous survey, which should take you about 3-5 minutes to complete.

Anonymity: The survey doesn't ask for your company's name or your name or any personal information. The information collected will be used for dissertation and other publications for the purpose of education.

Reasons: Some reasons you might want to participate in this research are if you are a leader in manufacturing. Some reasons you might not want to participate in this research are if you do not work in manufacturing or have no experience with Industry 4.0

Participation Choice: The choice to participate or not is yours; participation is entirely voluntary. You also can choose to answer or not answer any question you like, and to exit the survey if you wish to stop participating. No one will know whether you participated or not.

Payments: You will not receive any payment or other compensation for participation in this study. There is also no cost to you for participation. You will be entered into a drawing for one of three $100.00 Amazon gift cards to be randomly drawn at the conclusion of the research. At the end of survey, you can add your contact information to be entered in random drawing. Your odds of winning are approximately 1 in 67.

Benefits: You can choose not to respond to any of the questions or close the browser to discontinue your participation at any time. After the survey, we would only be able to withdraw your previously submitted data if you have provided your email. If you do want your research data withdrawn, we ask you do so within 30 days of completing the survey.

IRBNet #: 2026880-2
Exempt Date: April 3, 2023
Indiana State University Institutional Review Board

Format: The survey asks questions about factors impacting readiness for Industry 4.0 adoption. You have been asked to participate in this research because you have a leader role in manufacturing and can provide information on these factors.

Risks: Although every effort will be made to protect your answers, complete anonymity cannot be guaranteed over the Internet. We expect that any risks, discomforts, or inconveniences will be minor, and we believe that they are not likely to happen. If discomforts become a problem, you may discontinue your participation.

Benefits: It is unlikely that you will benefit directly by participating in this study, but the research results may benefit but the research results benefit the stakeholders, including policy makers, manufacturing leaders, academia, companies, and others. It may also apply to other countries and industries. Finally, it will help future researchers in developing strategies to accelerate the adoption of Industry 4.0.

If you have any questions, please contact Yogesh Bhutani, Principal Researcher, Ph.D. Candidate. Phone: (281) 752-6835, Email: ybhutani@sycamores.indstate.edu

If you have any questions about your rights as a research subject or if you feel you have been placed at risk, you may contact the Indiana State University Institutional Review Board (IRB) by mail at Indiana State University, Office of Sponsored Programs, Terre Haute, IN 47809, by phone at (812) 237-3088 or by email at irb@indstate.edu.

Exempt Approval

Indiana State University
More. From day one.

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812-237-3088
Fax 812-237-3092

DATE:	April 3, 2023
TO:	Yogesh Bhutani
FROM:	Indiana State University Institutional Review Board
STUDY TITLE:	[2026880-2] US MANUFACTURING READINESS FOR INDUSTRY 4.0
SUBMISSION TYPE:	Revision
ACTION:	DETERMINATION OF EXEMPT STATUS
DECISION DATE:	April 3, 2023
REVIEW CATEGORY:	Exemption category #2

Thank you for your submission of Revision materials for this research study. The Indiana State University Institutional Review Board has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations (45 CFR 46). You do not need to submit continuation requests or a completion report. Should you need to make modifications to your protocol or informed consent forms that do not fall within the exempt categories, you will have to reapply to the IRB for review of your modified study.

Internet Research: If you are using an internet platform to collect data on human subjects, although your study is exempt from IRB review, ISU has specific policies about internet research that you should follow to the best of your ability and capability. Please review Section L. on Internet Research in the IRB Policy Manual.

Informed Consent: All ISU faculty, staff, and students conducting human subjects research within the "exempt" category are still ethically bound to follow the basic ethical principles of the Belmont Report: 1) respect for persons; 2) beneficence; and 3) justice. These three principles are best reflected in the practice of obtaining informed consent.

If you have any questions, please contact Ryan Donlan within IRBNet by clicking on the study title on the "My Projects" screen and the "Send Project Mail" button on the left side of the "New Project Message" screen. I wish you well in completing your study.

APPENDIX C – COPYRIGHT PERMISSIONS

VDMA Permission

From: Dietmar Goericke <Dietmar.Goericke@vdma.org>
Sent: Friday, December 16, 2022 8:08 AM
To: Yogesh Bhutani <ybhutani@sycamores.indstate.edu>
Subject: AW: [EXTERNAL] VDMA Industry 4.0

Dear Yogesh Bhutani,

Please feel free to use the VDMA readiness model for your research.

I wish you good success.

Viele Grüße | Kind Regards

Dietmar Goericke

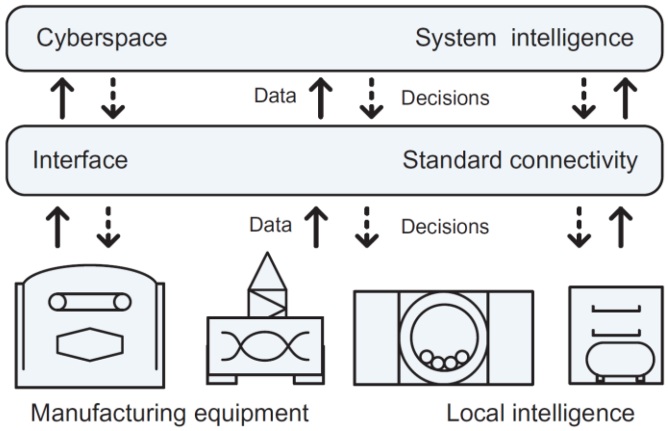
Geschäftsführer | Managing Director

VDMA FuE | VDMA RTD

FKM e.V. | FVV e.V. | FLT e.V.

dietmar.goericke@vdma.org | T +49 69 6603-1821

VDMA e.V. | Lyoner Str. 18 | 60528 Frankfurt am Main



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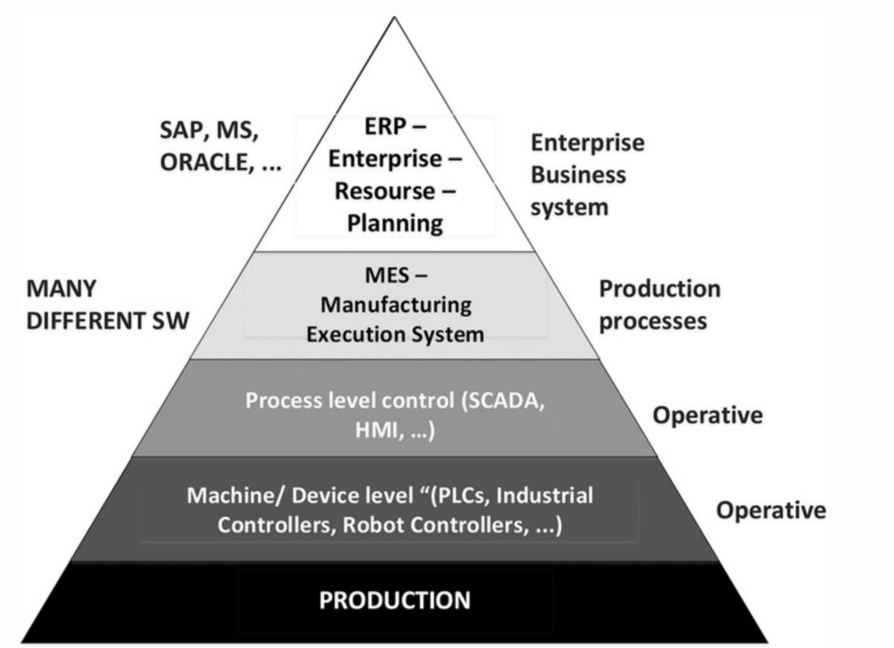


From: Michael Auer <auer@cti-online.net>
Sent: Monday, July 17, 2023 10:49 AM
To: Yogesh Bhutani <ybhutani@sycamores.indstate.edu>
Cc: support@online-journals.org
Subject: Re: Copy right permission

You can do so, no problem.

Michael Auer

Executive Editor

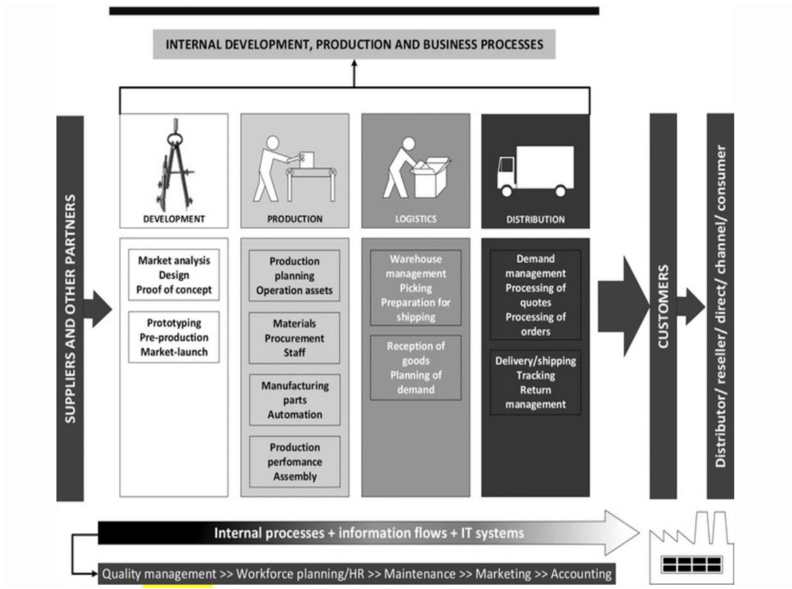
Am Mo., 17. Juli 2023 um 17:30 Uhr schrieb Yogesh Bhutani <ybhutani@sycamores.indstate.edu>:

I am a doctoral candidate at Indiana State University. I will like to include the pyramid graphic from the paper: Form Rojko, A., Industry 4.0 Concept: Background and Overview, ECPE European Center for Power Electronics e. V., Nuremberg, Germany, 11, 2017. I will cite the graphic appropriately.

Please let me know if I need to provide additional information.

Regards,

Yogesh



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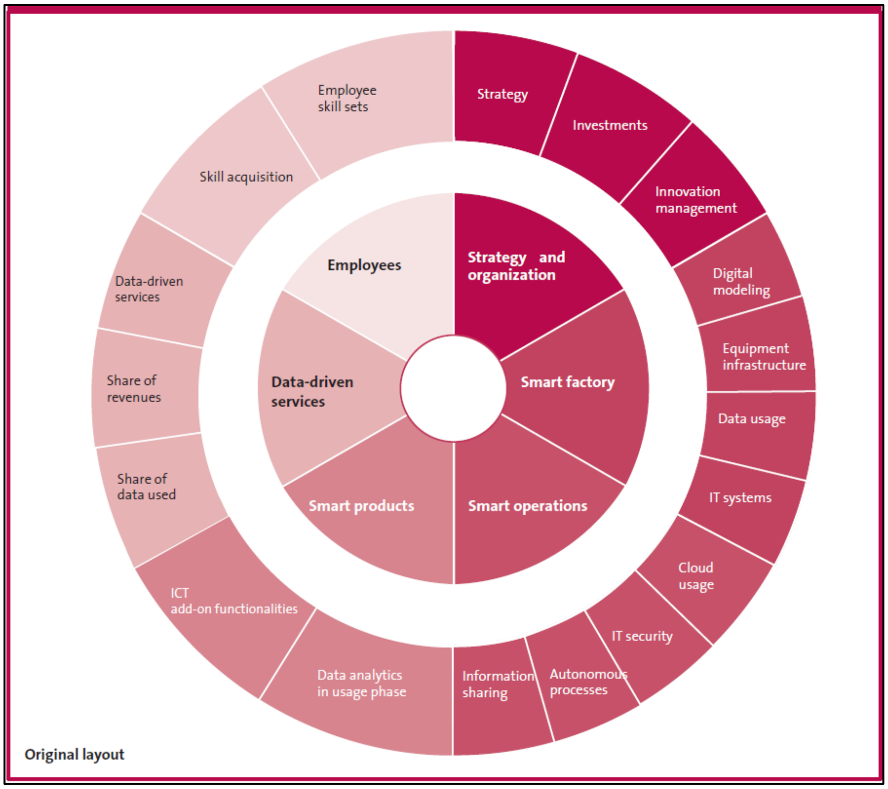

From: Dietmar Goericke <Dietmar.Goericke@vdma.org>
Sent: Friday, June 30, 2023 4:20 AM
To: Yogesh Bhutani <ybhutani@sycamores.indstate.edu>
Subject: Re: [EXTERNAL] VDMA Industry 4.0

Dear Yogesh Bhutani,

no problem if use give the right citation and reference for this graphic in your dissertation.

All the best for you.

Viele Grüße | Kind Regards

Dietmar Goericke

Geschäftsführer | Managing Director

VDMA FuE | VDMA RTD

FKM e.V. | FVV e.V. | FLT e.V.

dietmar.goericke@vdma.org | T +49 69 6603-1821

Readiness level	*Description*	*Criteria*
Level 0: Outsider	• Either no requirement is met, or Industry 4.0 is unknown and irrelevant.	0
Level 1: Beginner	• Pilot initiatives in Industry 4.0, investments in single area. • Infrastructure partially meets future requirements. • Skills are found in few areas.	0 < Points ≤ 50
Level 2: Intermediate	• Incorporating Industry 4.0 into the company strategy. • Investments in noticeable number of areas. • Partial automation in collection of data. • Skills available in some areas to pursue Industry 4.0.	50 < Points ≤ 90
Level 3: Experienced	• Strategy formulated. • Investments in significant number of areas. • Infrastructure may be upgradable. • Security in place for the information technology systems.	90 < Points ≤ 120
Level 4: Expert	• Industry 4.0 strategy in use. • Investment achieved in almost the entire organisation • Large amounts of data collected automatically and used for optimisation purposes. • Availability of add-on information technology functionality in the products.	120 < Points ≤ 145
Level 5: Top performer	• Industry 4.0 strategy implemented and monitored for progress. • Industry 4.0 investments in the entire company • Infrastructure satisfies all Industry 4.0 requirements.	145 < Points ≤ 160

From: Schutte, Corne, Prof [corne@sun.ac.za] <corne@sun.ac.za>
Sent: Thursday, June 29, 2023 11:31 PM
To: Yogesh Bhutani <ybhutani@sycamores.indstate.edu>
Cc: sajie@saiie.co.za
Subject: Re: [EXTERNAL] Copy right permission

Hi Yogesh

Yes, you are welcome, with the correct citing to the article.

Regarxs

Prof Corne Schutte | PhD PrIng FSAIIE | PhD PrEng FSAIIE Voorsitter en Professor: Departement van Bedryfsingenieurswese | Chairman and Professor: Department of Industrial Engineering
Ingenieurswese | Engineering
Ingenieurswese | Engineering
e: corne@sun.ac.za | t: +27 21 808 4234 | a: Industrial Engineering Building, Banghoek Rd, Stellenbosch

When	Where	Jobs Destroyed	Jobs Created	Predictor
2016	worldwide		900,000 to 1,500,000	Metra Martech
2018	US jobs	13,852,530*	3,078,340*	Forrester
2020	worldwide		1,000,000-2,000,000	Metra Martech
2020	worldwide	1,800,000	2,300,000	Gartner
2020	sampling of 15 countries	7,100,000	2,000,000	World Economic Forum (WEF)
2021	worldwide		1,900,000-3,500,000	The International Federation of Robotics
2021	US jobs	9,108,900*		Forrester
2022	worldwide	1,000,000,000		Thomas Frey
2025	US jobs	24,186,240*	13,604,760*	Forrester
2025	US jobs	3,400,000		Science Alert
2027	US jobs	24,700,000	14,900,000	Forrester
2030	worldwide	2,000,000,000		Thomas Frey
2030	worldwide	400,000,000-800,000,000	555,000,000-890,000,000	McKinsey
2030	US jobs	58,164,320		PWC
2035	US jobs	80,000,000		Bank of England
2035	UK jobs	15,000,000		Bank of England
No Date	US jobs	13,594,320*		OECD
No Date	UK jobs	13,700,000		IPPR

Hi Yogesh,

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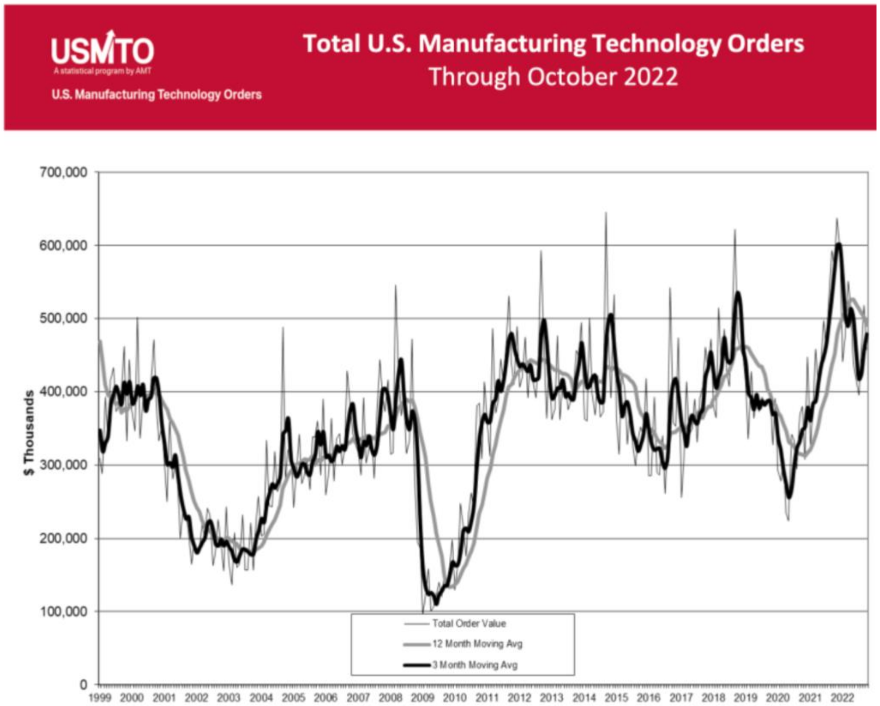

From: Chris Chidzik <CChidzik@amtonline.org>
Sent: Friday, July 28, 2023 12:04 PM
To: Yogesh Bhutani <ybhutani@sycamores.indstate.edu>
Subject: USMTO Graphic Copyright

Hey Yogesh,

A colleague forwarded me your inquiry about using a chart from the December 2022 USMTO press release in your dissertation. You are certainly free to use the data and graphics contained in the press release as long as you cite the data or graphic you use as coming from "AMT's December 2022 USMTO Report" or from whichever release you found the graphic. There are sometimes revisions to the data, so it's best for version control to cite from which release the data was drawn.

If you would like to see the most recent press release with orders through May 2023, you can find it by following this link.

Let me know if you have any questions or we can help with anything else.

Chris

Christopher Chidzik