**University of Pécs**

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# Transformative Impact of Industry 4.0 Technologies on the UK Manufacturing Sector

Doctoral Dissertation

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# Declaration of Originality

I, the undersigned, hereby declare that this doctoral dissertation is the result of my own independent research and is written solely by me using the literature and resources listed in the references.

Muhammad Rahim Ejaz

## Acknowledgements

I was so excited when I started my PhD at the University of Pecs. Soon I realized that it was going to be a challenging task and much more difficult for me in contrast to my expectations. Well, I may not be good at many things in my life but I am not a quitter and I am a firm believer in hard work. I learned new concepts and upgraded my knowledge base to help me through the whole PhD process.

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# List of Abbreviations

| | |
|---|---|
| 3-D Printing | Three Dimensional Printing |
| AI | Artificial Intelligence |
| AM | Additive Manufacturing |
| AR | Augmented Reality |
| BDA | Big Data Analytics |
| CC | Cloud Computing |
| CDO | Chief Digital Officer |
| CF | Concept Flexibility |
| COBOTs | Collaborative Robots |
| CPSs | Cyber-Physical Systems |
| CPSS | Cyber-Physical Social System |
| CPU | Central Processing Unit |
| CS | Cyber Security |
| ERP | Enterprise Resource Planning |
| EV | Electric Vehicle |
| HP | Hewlett-Packard |
| ICT | Information and Communication Technology |
| IIoT | Industrial Internet of Things |

| | |
|---|---|
| IoS | Internet of Services |
| IoT | Internet of Things |
| IT | Information Technology |
| JIT | Just in Time |
| MIS | Management Information System |
| OE | Operational Efficiency |
| OEE | Overall Equipment Effectiveness |
| PF | Prototype Flexibility |
| PPC | Production Planning and Control |
| QFD | Quality Function Deployment |
| R&D | Research & Development |
| RBV | Resource Base View |
| TPM | Total Productive Maintenance |
| VR | Virtual Reality |
| VW | Volkswagen |
| WEF | World Economic Forum |
| WTO | World Trade Organization |

## 1. Introduction

The introduction of Industry 4.0 has brought a revolution not in the IT industry but in the manufacturing sector and in the society. The impact of Industry is so huge that even the concept of smart cities has been formulated based in Industry 4.0 technologies. The motivation of the study is driven from the significance of the Industry 4.0 technologies. In the manufacturing sector, there are various domains that are being affected by the Industry 4.0. However, this study decided to focus on the variables of OEE and competitiveness in context with the size of the organization. In the research domain of operations and production management, the research interest is being developed to study the impact of Industry 4.0 technologies on the manufacturing sector. The research focuses on OEE and competitiveness as these are also relevant topics within this research domain. The study aims to explore the significance of the Industry 4.0 technologies on the above mentioned areas of the interest. This will help us to understand the nature of the relationship among them and will give us the insight to investigate the impact of the Industry 4.0 on the manufacturing sector.

A rapid industrial development has been seen in modern industrial age to improve the lifestyle in the society. According to Łabędzka (2021) Industry 4.0 offers an opportunity of digital transformation in industrial development. Xu (2020) states that Industry 4.0 affects the society and it transforms the meaning of work from work for life to life as work. In every era, there is a need for technological development and advancement to meet the challenges of present time and challenges ahead of time. According to Xu (2020), Machado et al. (2019), Zhang & Chen (2020), Javaid et al. (2021), Khan & Javaid (2021) and Mateo & Redchuk (2022) Industry 4.0 is termed as fourth generation revolution. It is characterized as advanced level of automation and integration in the manufacturing industry. It represents an embedded and connected system of technologies that has blurred the boundaries between real and virtual world. Increase in demand for energy consumption and subsequently environmental pollution are one of the major challenges that are being faced by the manufacturing sector today. To work profitably in the given changing environment, organizations have to restructure themselves including their resources so that they can contribute to the industrial growth across the globe.

Kumar et al. (2020) argue that new manufacturing technologies are necessary for sustainable manufacturing in organizations. It is believed that production systems based on sustainable manufacturing processes are energy efficient as they help to reduce the consumption of energy and resources. Digitization of manufacturing processes can help to make manufacturing processes more efficient and more sustainable. Karnik et al. (2022) state that Industry 4.0 has the ability to make substantial changes in the production, quality, lead time, cost, employment and economic growth. Kumar et al. (2020) asset that Industry 4.0 is a socio-technical concept in which technological, social and organizational processes are interconnected. Investment in knowledge acquisition is critical in order to implement sustainable practices in manufacturing organizations.

The phenomenon of digital transformation has become more eminent than ever in the recent years. Especially after the surge of pandemic, organizations are transforming themselves at a faster pace now by adopting digital technologies and by introducing novel digital business models to address the needs of modern times. The big economies went into an economic shock after being hit by the novel corona virus. It is worst of the kind known to the mankind. Mohapatra et al. (2021) posit that now it is more critical for manufacturing sector to adopt digital technologies especially after the lockdowns and supply chain abruptions. When many big manufactures were closed during the lock downs, they would have not faced the situation if they had smart technologies interconnected with IoT. In that case, machinery and tools could have been used remotely. In other words, pandemic is one of the major forces behind digital transformation of the manufacturing sector. Matarazzo et al. (2021) avow that digital business models incorporated with digital technologies will open new avenues of opportunities and bring more value to the organizations. Digital technologies are already shaping businesses and their interaction with consumers through multiple communication touch points. Digital technologies have the ability to revolutionize existing business models and increase customer value by making the business more customer focused.

Chikwendu et al. (2020) and Hung et al. (2022) argue that importance of process improvement can be highlighted by adopting an equipment maintenance approach and one of the most common equipment maintenance approach is total productive maintenance (TPM). TPM is a proactive rather a reactive approach, it provides an aggressive attitude towards problem solving, reducing cost, improving quality and increasing production capacity. According to Hung et al. (2022) TPM deals with the reduction of production losses and increase in the production time. TPM identifies “six big losses” namely, downtime loss, setup/adjustment, defect loss, start up, speed loss and idling/minor stoppages. TPM measures the performance of the production system emphasizing on the core quantitative metric known as Overall Equipment Effectiveness (OEE). It is an effective way to measure performance of one or more machines/workstations in a production line or a manufacturing unit. Saarikko et al. (2020) postulate that developing a strategy has core importance in the implementation of digital transformation as (Hung et al. 2022) state that OEE plays a critical role in the strategic performance measurement of a manufacturing firm.

When organizations develop a technology-oriented culture and train workforce with digital skills then it becomes easy for an organization to cope with the upcoming challenges that can be addressed only through digital technologies. According to Saarikko et al. (2020) there are two main reasons to adopt digital technologies. First, digital technologies boost innovation and the second is that digital technologies have low entry barrier so firms of all sizes can implement in their respective organizations. Digital technologies have a potential to become either transformative or disruptive for an organization. They can bring an organization to a leading position in a competitive market or create a new niche in the existing industry. However, the fruit of digital technologies cannot be reaped without proper understanding of digital technologies and a strategy. Any given organization cannot benefit from the digital technologies unless they fully understand the true potential of their organization and knowledge to adopt the most suitable digital technology as per their requirement.

The introduction of smart technologies in the field of manufacturing has reformed manufacturing as a source of competitive advantage. According to Parthasarthy and Yin (1996) the intense pressure on the companies forces them to develop a competitive advantage through smart technologies in manufacturing. However, it is stressed by the researchers that in order to truly translate that effect, firms have to make overall changes in their organizational structure. In order to achieve this objective, companies require a strategy which they can follow to achieve a competitive edge. In case of manufacturing companies' managers often try to formulate strategies focusing on cost cutting or quality enhancements in their manufacturing processes to achieve cost or quality based competitiveness. Hayes and Pisano (1994) argue that any strategy whether it is JIT or TQM that applied in the manufacturing process to improve cost effectiveness or quality will not lead a company anywhere unless companies start to think of them as a way forward not as a solution. The long-term goal for companies should not be acquiring improved manufacturing processes but to build a sustainable competitive edge that can last and cannot be bought or build by other competitors. Gómez & Lafuente (2019) state that an organization should maintain valuable resources with itself which cannot be copied to achieve sustainable competitiveness. It is a multidimensional concept and the relationship between capabilities and resources are always a major focus in understanding the concept of sustainable competitiveness.

One of the examples of manufacturing competitiveness is flexible products design. It has been witnessed by Li et al. (2012) that there is a strong relationship between product design and consumer preferences. It is also a known fact that modular product designs gain more consumer attention than non-flexible product designs. This is a major reason why companies opt of modular product designs to gain maximal market share and to beat their competitors. Bonvoisin et al. (2016) define product modular design as "an activity of designing a product that is made up of modules" (Bonvoisin et al. 2016 p.02). According to Li et al. (2012) now manufacturers have realized that the product designs preferred by the consumers are essential for firm's success and survivability in global competitive environment. Wei et al. (2017) also posit that a platform that allows product design flexibility is needed in order to reduce uncertainty, upgrade products and improve development cost and time. In order to do that they have adopted the strategy of quality function deployment (QFD) which enables the manufacturers to produce products according to the consumer preferences and it also covers the changing dimension of consumer preferences over time. QFD defined as "an overall concept that provides the means of translating consumer requirements into appropriate technical requirements for each stage of product development and production" (Chan et al. 2002, p.463). Saenz et al. (2018) argue that now market has been shifted to "on demand" based economy where consumer demand decides what to buy and manufacturer has to produce accordingly. According to Veryzer (1999) consumer preferences are behavioural responses based on their innate desires which can be influenced by their social environment, cultural and other factors. Tripsas (2008) propounds that it is discontinuity in the consumer preferences that forces manufacturers to look for new technologies and manufacturing process in order to produce new flexible products.

This thesis is focussed on the factors that are involved in the decision-making process of flexible product development. Organisations need to be innovative and competitive while designing and launching flexible products into the market as competition can force the companies for continuous R&D to produce new products constantly keep up with the market forces. Sometimes, organizations are not sure what might be the right strategy for product development due to rapid changes in the consumer preferences. Organisations develop flexible products in terms of their functionality to reduce uncertainty to cater the wide range of consumer preferences. Products that can be used in multiple variations and can be reconfigured into different settings so that consumers can use them according to their need and desire are called flexible products. For example, electric shavers come with different trimmer sizes. This option gives consumers multiple choices to use the electric shaver. Nes et al. (2005) argue that flexible products last longer because they cannot be replaced by any other product so it might give companies a level of certainty in consumer market in terms of consumer preferences.

### 1.1 Purpose of this study

The purpose of the study is to determine the effects of the implementation of Industry 4.0 technologies on the manufacturing sector. The implementation of Industry 4.0 technologies is being assessed based on organizational size, OEE and competitiveness. The scientific literature available related to these topics have shown evidence that there is a connection between them and the implementation of the Industry 4.0 technologies. In the light of the literature, the below mentioned hypothesis are being developed to be tested against the data which will be collected. The hypotheses are divided into different sections. The analysis of these hypotheses will tell us how the implementation of Industry 4.0 affects them and whether these variables play a significant role in it or not.

The present literature extensively talks about the use and benefits of the Industry 4.0 technologies but there is research gap with respect to the organizational size and implementation of the Industry 4.0 technologies. This study has developed a list of prerequisites that an organization should complete before the implementation of Industry 4.0 technologies. The completion of these prerequisites determines the readiness of the organization in order to implement Industry 4.0 technologies, leading to the improvement of OEE and manufacturing competitiveness. The present literature have extensively discussed about the OEE and manufacturing competitiveness, however, literature on Industry 4.0 technologies readiness and its implementation is limited. The hypothesis related to organizational size is related to the implementation and their readiness. This will help to determine the awareness of the organization's management about digital transformation with respect to their organization's size.

In the manufacturing sector, the OEE is an important variable that determines the manufacturing performance of the organizations. When organizations develop competitiveness based on their manufacturing, it is crucial to improve OEE in this regard. There are six factors in the OEE and unless they have been improved, it is not possible to improve OEE. This study has identified 8 main Industry 4.0 technologies while more are underway. This study has developed the hypothesis related to OEE not only to test Industry 4.0 technologies with OEE as whole but also each Industry 4.0 technology has been tested with each OEE factor separately. It will help to provide a clear picture to understand which technology has what kind of influence on each factor of the OEE.

Competitiveness is one of the major driving forces that motivate organizations to implement Industry 4.0 technologies. Nine components of competitiveness have been derived from the literature and these components have been tested against the Industry 4.0 technologies independently to identify the relationship among them. The competitiveness variables are exclusively related to the manufacturing competitiveness of the organizations. These variables act as performance indicators for manufacturing competitiveness. While the prerequisites for implementation of industry 4.0 technologies also act as the drivers to obtain manufacturing competitiveness in respect with Industry 4.0 technologies.

These drivers and performance indicators have not been explored along with the Industry 4.0 technologies along with the role of organisation size yet and this study will determine their significance with respect to the Industry 4.0 technologies. The thesis aims to fill this knowledge gap with the literature and empirical results. It is important to understand that if organisation size really matters to obtain Industry 4.0 readiness which is vital for its implementation. The implementation of Industry 4.0 technologies lead to the OEE improvement and manufacturing competitiveness. This also helps to understand the viability of the Industry 4.0 technologies in several manufacturing firms across the manufacturing sector.

**Organizational Size**

H1: There is a positive influence of organizational size on the time since Industry 4.0 technologies been implemented.

H2: There is a positive influence of organizational size on the implementation of Industry 4.0 technologies.

H3: There is a positive influence of organizational size on the organizational readiness for Industry 4.0 technologies.

**OEE**

H4: There is a positive relationship between OEE and the Industry 4.0 technologies.

H4.1: There is an inverse relationship between Industry 4.0 technologies and downtime.

H4.2: There is an inverse relationship between Industry 4.0 technologies and setup time.

H4.3: There is an inverse relationship between Industry 4.0 technologies and defective products.

H4.4: There is an inverse relationship between Industry 4.0 technologies and performance loss.

H4.5: There is an inverse relationship between Industry 4.0 technologies and speed losses.

H4.6: There is an inverse relationship between Industry 4.0 technologies and planned/unplanned stoppages.

**Competitiveness**

H5: There is a significant impact of Industry 4.0 technologies on competitiveness

H5.1: There is a significant impact of Industry 4.0 technologies on reduction in resource usage

H5.2: There is a significant impact of Industry 4.0 technologies on reduction in production cost

H5.3: There is a significant impact of Industry 4.0 technologies on increased manufacturing capabilities

H5.4: There is a significant impact of Industry 4.0 technologies on increased R &D

H5.5: There is a significant impact of Industry 4.0 technologies on increased product quality

H5.6: There is a significant impact of Industry 4.0 technologies on increase mass customization

H5.7: There is a significant impact of Industry 4.0 technologies on increased operational efficiency

H5.8: There is a significant impact of Industry 4.0 technologies on flexible manufacturing process

H5.9: There is a significant impact of Industry 4.0 technologies on more flexible product design

## 1.2 Structure of the Dissertation

The structure of the dissertation is as follows.

**First Section**

The first chapter of the study provides the introduction of the topic and the purpose of the study has been introduced. The motive and the nature of the study have also been discussed. The main objectives of the study which this study intends to achieve are also being discussed in this section. This section also highlights the importance of the impact of Industry 4.0 technologies on the various dimensions of manufacturing.

**Second Section**

The second section is comprised on the literature review of the study. The literature has been analysed in detail and all the possible dimensions are covered in this section. These include the process of digital transformation and the concept of digitalization. Moreover, this section also highlights the importance of prerequisites and readiness of the organization before the implementation of Industry 4.0 technologies. Furthermore, the impact of Industry 4.0 on flexible products and flexible manufacturing has also been discussed. Additionally, the impact of Industry 4.0 on competitiveness in regard to smart manufacturing has also been discussed in this section of the study. A theoretical framework for competitiveness and knowledge management is also given in this section. Also, the concept of OEE and its relationship with the Industry 4.0 technologies has also been discussed in extensive detail.

**Third Section**

The theoretical findings of the study have been elaborated in the third section of the study. A theoretical model is being presented to grade the readiness level of organizations for Industry 4.0 that has been developed. Furthermore, a theoretical model for organizational competitiveness in terms of operational efficiency has been developed.

**Fourth Section**

Research design and the methodology of the study have been formulated in this section to verify the statements made in the theoretical models empirically. The data collection technique, nature of the questionnaire and the data processing techniques that this study intended to use are also discussed in detail in this section of the study. The interpretation approach that this study has adopted has been explained in this section of the study.

**Fifth Section**

The results of the study are presented in the fifth section. The nature of statistical tools and why these tools are being used are explained in this section. The SPSS software package has been used for the purpose of data analysis and the tests has been run according to the nature of the questions given in the questionnaire. The best suited test has been run by using SPSS as per scientific literature to achieve accurate results as much as possible. These findings has also been analysed and supported by scientific literature where possible.

**Sixth Section**

The sixth section is based on the recommendations and suggestions that this study made based on the results. The recommendations are given to the managers and the policy makers of the organizations in this regard. In this section, the study also highlighted the limitations and the contributions of the study.

**Seventh Section**

The seventh section, the concluding remarks has been made addressing the nature of the study and what study aimed to achieve. The findings of the study highlighted the importance of the Industry 4.0 along with various factors which are probably equally important as technology. This section concludes the whole research and explains how this research has contributed to the literature.

## 1.3 Abstract

The study emphasizes the importance of Industry 4.0 technologies and its benefits on manufacturing organizations. Industry 4.0 is a fourth generation industrial revolution and it is based on autonomous manufacturing. This concept was initially floated in Germany and similar concepts were also emerged in various countries later on. One of the other concepts is smart manufacturing which emerged in the US. These concepts may look similar but Industry 4.0 covers a wide range of disciplines as it not only connects with manufacturing, but it also connects with society, government, academia and the environment.

This study has a limited scope within the manufacturing domain and analyses the impact of Industry 4.0 on OEE and competitiveness with respect to organisation size. The research questions have been formulated to cater the domains of OEE and competitiveness. Organizational size is being used as dependent variable and Industry 4.0 technologies as an independent variable in the empirical analysis. The variables of OEE, competitiveness have been empirically tested against them. The total time duration of the completion of the thesis is 4 years and 6 months.

The study has also shed light on the importance of digital transformation of an organization as it is important for an organization to implement Industry 4.0 technologies. The study has also emphasized the relationship of flexible products and competitiveness in the literature and the empirical findings have also contributed to the scientific literature in this regard. Most importantly, the thesis has formulated the prerequisites of Industry 4.0 technologies to be implemented to evaluate the readiness of a firm before Industry 4.0 technologies could be implemented. These prerequisites also act as the drivers of the operational competitiveness for a manufacturing firm. The impact of Industry 4.0 on OEE is also discussed in this study

and the empirical findings of the study have also contributed to understand this subject in a better way.

The thesis has extensively analysed the operational competitiveness variables which also act as the performance indicators. There is a significant impact of Industry 4.0 technologies on the operational competitiveness. Several variables of competitiveness have shown a positive impact of Industry 4.0 technologies over them.

The empirical findings of the dissertation will help the researchers in future and to gather more ideas for their research in the similar research domain. This research will not only play the role of a guide for the researchers in the academia but will also provide a roadmap to the managers and policymakers working in the organizations.

# 2. Literature

## 2.1 Industry 4.0

This chapter of the dissertation is based on the literature review of the topic in question. The concept of Industry 4.0 has been discussed in an extensive detail along with its beginning from the digital transformation and how organizations make their decisions towards it. The literature has also discussed the complete implementation process of the Industry 4.0 technologies along with its prerequisites. The concept of manufacturing performance is also being reviewed in thoroughly in the context of OEE. The different dimensions of competitiveness are also being debated in the study in the relation with the Industry 4.0 technologies.

According to Abdirad et al. (2020), Duan & Da Xu (2021), Sigov et al. (2022), Xu (2020), Sony & Aithal (2020), Castelo-Branco et al. (2019), Gorkhali (2022), King et al. (2020) and Kumar et al. (2022) Industry 4.0 plan was announced by German government in Hannover fair in 2011. Initially, it was aimed to boost the competitiveness in the national manufacturing but it triggered a revolution in the manufacturing sector all over the world. According to Mariani et al. (2019) originally Industry 4.0 was defined as "Industry 4.0 involves the technical integration of cyber-physical systems (CPSs) into manufacturing and logistics and the use of internet of things and Services in the industrial processes." Abdirad et al. (2020) have defined Industry 4.0 as "a comprehensive introduction of information and communication technology (ICT) as well as their connection to IoT, services and data, which enables real time production". King et al. (2020) argue that it is a next evolution of the industrial automation with increasing levels of communication and information available of the devices. Mateo & Redchuk (2022) have defined CPS as "a system with integrated computational and physical capabilities that can be interfaced in different ways". Kim (2017) states that CPS is an integration of cyber systems with physical equipment. According to Li (2018) and Dalenogare et al. (2018) Industry 4.0 focuses on smart manufacturing and CPS that helps in the integration of digital technologies like 3D printing, Cloud Computing and IoT. According to Gorkhali (2022) Industry 4.0 has three stages of implementation. First stage is the introduction of smart technologies that take control over usage of resources and the whole manufacturing process. At the second level, smart technologies are being integrated together to form a CPS which helps to carry out the transition phase from conventional manufacturing to smart manufacturing. At the third stage, CPS integrates with humans to create human-machine work environment. It will assist human operators to control, monitor and perform all the manufacturing functions. This platform will establish a collaborative manufacturing ecosystem that can help to design sustainable digital manufacturing entities. Lu (2017) argue that CPS functions as an infrastructure that provides a foundation for integration of physical manufacturing facilities with internet and computer applications to form a system that relies on networking and information processing technologies. Industry 4.0 advocates a new phase of industrial revolution which is technology and innovation driven. However, the term Industry 4.0 is described as "fourth generation of industrialization" but the term "revolution" is also being used in academic literature. Some other terms are also used in the academic literature but the most common term is "smart manufacturing." The word smart means an object with additional features and enhanced capabilities; when it is coupled with manufacturing then it means a connected manufacturing environment with the help of internet and other communication tools (Culot et al. 2020, p. 12).

According to Culot et al. (2020) the idea of Industry 4.0 is originally focused on the impact of evolving technologies in the world of manufacturing. Zhang & Chen (2020) and Mateo & Redchuk (2022) have termed Industry 4.0 as a significant change in the manufacturing sector as it enhances manufacturing system efficiency and performance. However, now the concept of Industry 4.0 is in relation with the transformation of consumer behaviours and society on the whole. The horizon of industry 4.0 is so vast and heterogeneous that it cannot be called a single technological breakthrough as it consists of several technologies. A combination of these technologies which are still evolving and function as enabling technologies is called Industry 4.0. Xu (2020) and Lasi et al. (2014) advocate that Industry 4.0 is comprised of theoretical concepts, technologies and organizational processes. It means that not only manufacturing system needs to be integrated but also the organizational units.

### 2.1.1 Conceptual Framework for Industry 4.0

Frank et al., (2019) have proposed a conceptual framework of Industry 4.0 which is based on two categories. These categories include baseline technologies and frontline technologies. One approach is smart factory which provides smart and intelligent production. Others include management, supply chain and consumer handling. The frontline technologies are *smart manufacturing, smart working, smart supply chain and smart products.* These are called frontline technologies because they offer a transformation of traditional manufacturing into advanced manufacturing which is known as smart manufacturing in the literature. On the other hand, Kumar et al. (2022) argue that in Industry 4.0, machines are connected and integrated through sophisticated baseline technologies which include CPS, IoT, BDA and etc.

According to Duan & Da Xu (2021) and Zhang & Chen (2020) CPS plays a critical part in the implementation of Industry 4.0. Choudhary & Mishra (2021) state that implementation of Industry 4.0 is a challenge as it not only requires money or government support but also requires technical education and skillset. CPS can be termed as an architecture to integrate all the components. If CPS is poorly designed then Industry 4.0 will not perform. CPS helps to integrate all the enabling technologies within the framework of Industry 4.0. These baseline technologies are also known as Industry 4.0 enablers and without them it is not possible to lay down the foundation of Industry 4.0 enabled smart manufacturing. These Industry 4.0 enabling technologies are further categorized and discussed in detail in the next section. This study uses a modified conceptual framework in the light of available literature. The modified conceptual framework can be seen in figure 1.

The research is focused on the aspect of smart manufacturing only as Industry 4.0 is a wide concept and this study has its own limitations. The motivation of choosing smart manufacturing is that it is related to the OEE and manufacturing competitiveness. The introduction of Industry 4.0 technologies in manufacturing can improve OEE, build competitiveness and help to achieve a closed loop manufacturing cycle. Frank et al. (2019) define smart manufacturing as a production system that can be adjusted automatically multiple times with flexible process lines to produce several products with different variations. It helps organizations to increase productivity, quality, flexibility, sustainability and mass production of customized products with better resource consumption.

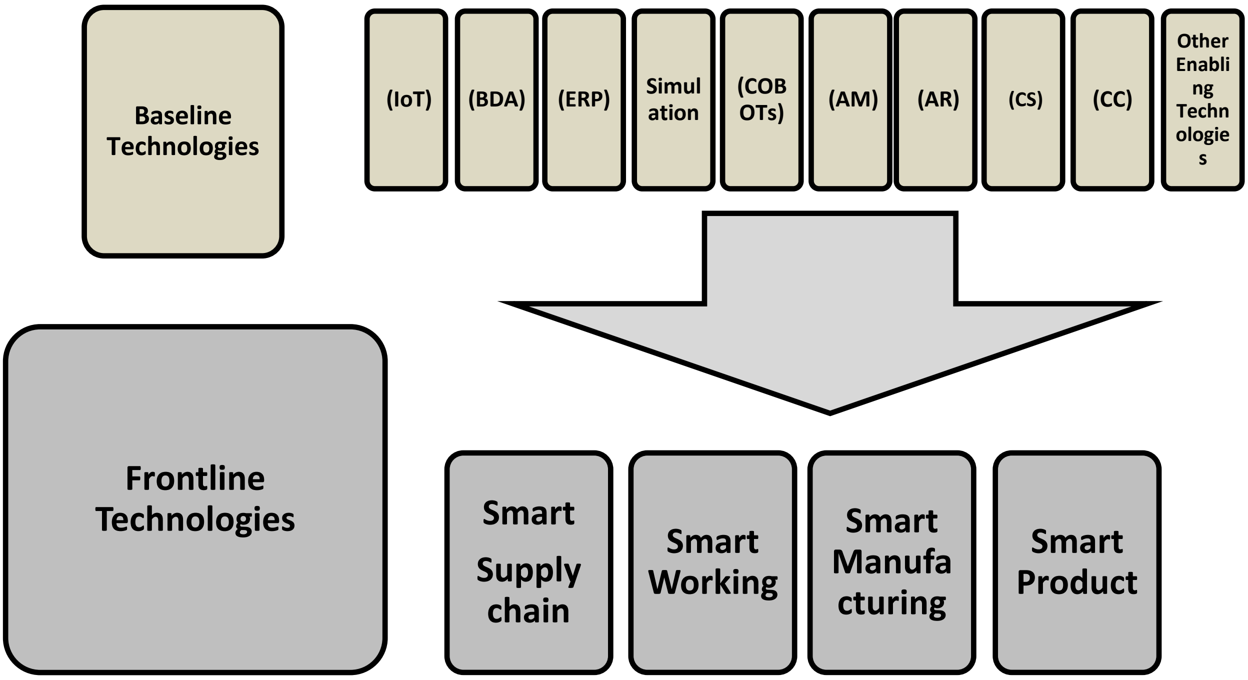


Figure 1: Industry 4.0 Conceptual Framework

Source: Frank et al. (2019)

### 2.1.2 Categorization of frontline Industry 4.0 Enablers

The concept of Industry 4.0 is rooted in the smart manufacturing as it has adjustable production lines that can adjust automatically with the production processes for multiple product types and conditions. It all helps to increase quality, productivity and flexibility of the production processes with respect to product customization and sustainability (Frank et al. 2019). Smart manufacturing is a central pillar in the Industry 4.0 concept as it deals with the internal operating activities of a manufacturing unit. However, on the other hand, smart products are supposed to add value to products externally for the purpose of customer integration and data integration with the production system. These two dimensions have a direct impact on the manufacturing process as smart manufacturing uses technologies to manufacture products within the production system while smart products use technologies related to product offering. Smart manufacturing is the beginning and core purpose of Industry 4.0 while a smart product is an extension. The roots of industry 4.0 lies in the smart manufacturing and from that point forward, it gets connect with the other associated processes of a manufacturing firm.

Two more dimensions of Industry 4.0 front end technologies are smart supply chain and smart working. They are considered as different dimensions as they add different value to manufacturing and products. The purpose of smart working and smart supply chain is to provide efficiency to the complementary operational activities. Smart supply chain uses technologies for horizontal integration of the manufacturing facility with the external suppliers for the improvement of raw material and final product delivery supply chain. The improvement is in respect with operational costs and delivery times. However, smart working uses technologies internally to support workers in their jobs; enabling them to be more productive and flexible to meet the smart manufacturing system requirements (Frank et al. 2019).

This dissertation is focused on the concept of smart manufacturing only as it is not possible to comprehend all the four dimensions. One other reason is that the smart manufacturing is of central importance in the Industry 4.0 concept and it is vital to explore it further in the context of manufacturing. The dissertation has chosen the dimension of smart manufacturing to research how technologies can help to obtain operational competitiveness within the manufacturing environment. The operational competitiveness can be measured through the equipment performance. The thesis explores the impact of Industry 4.0 enabling technologies on the manufacturing environment of a manufacturing facility within the manufacturing sector.

### 2.1.3 Smart Manufacturing

Mittal et al. (2017) state that the term smart manufacturing was originally came from United States which is now popular across the globe. According to Kusiak (2017) smart manufacturing has its roots since half past twentieth century. The concept of smart manufacturing has evolved a lot in last three decades from simple digitization to computer integrated manufacturing with the help of IoT and other technologies. Khan & Javaid (2021) state that IoT is an industrial technology that provides better manufacturing satisfaction. IoT helps to create a smart factory based on sensors, actuators and other modules. Reduction of industrial waste and improvement in products are one of the major concerns for the manufacturing process management. Smart manufacturing in a broader spectrum can be explained as machines that communicate with other machines as they are networked together and equipped with data needed for performing already programmed and scheduled tasks.

According to Shao et al. (2021) initial research in the field of smart manufacturing were mainly focused on different technologies that are being used in manufacturing such as CC, BDA, IoT etc. However, current research in this area are more in depth as they discuss planning, designs, manufacturing systems, human resources and other relevant aspects. Tasks like all round monitoring and performance optimization can be performed by smart manufacturing with the help of simulation and big data. According to Kang et al., (2016) smart manufacturing aims for sustainable growth through management and other manufacturing variables such as productivity, quality, delivery and flexibility based on modern technology.

Zheng et al. (2018) and Mittal et al. (2017) state that in Smart manufacturing; Industry 4.0 technologies collect data from the machines to improve managerial performance, manufacturing processes and precise decision making. In order to do that, the very first step is the collection of manufacturing input data. Khan & Javaid (2021) argue that IoT helps to capture real-time data and information by using a virtual management system. It can not only help to minimize the errors in the on-going production but also has the capability of prediction of upcoming situations. This data can be stored at cloud-based data servers so that it can be accessed remotely. Smart manufacturing also helps to achieve more rapid and bigger production capacity to facilitate growing needs. It can also help in production planning, product development, smart consumption of resources, self-learning and self-regulation within the production system.

Now smart manufacturing has gone one step further as data is being used in product development. It will help to identify key features and requirements that are demanded by the consumer market. This data can also be used for optimization of networking and resource allocation for better manufacturing planning. This data can also be used for the prediction of probable faults and their diagnoses of the manufacturing process. It will lead to an automated and initiative-taking maintenance of the manufacturing processes. AR is a technology that can be used for predictive maintenance with less possible disruption in the manufacturing process. According to Khan & Javaid (2021) IoT is one of the best approach that can be used for predictive maintenance which can help to save costs. Shao et al. (2021) suggest that data mining techniques can also be used for the purpose of production operations improvement with respect to quality.

Smart manufacturing has been further divided into six different dimensions which include *integration, virtualization, automation, traceability, flexibility* and *energy management.*

**Integration:** Integration is the first step towards digitization at any given manufacturing facility. Li (2018) and Łabędzka (2021) argue that the core concept of Industry 4.0 is integration. It helps in decision making and reduces human dependency. Xu (2020) states that Industry 4.0 requires horizontal, vertical and end to end integration. Technologies like ERP are required to develop an integrated network between all sections including supply chain and administration for smooth flow of information. Gorkhali (2022) say that integration of Industry 4.0 enabling technologies is a challenge as it requires a framework. According to Frank et al. (2019) a communication system is needed so that transparency and control can be achieved. Simulation is also used to simulate different operational and production processes so that error free production can be achieved. Bellini et al. (2022) posits that Industry 4.0 enabling technologies can be used to collect real time data and connect/integrate other machines and factories with the help of a combination of software and hardware.

**Virtualization:** Some technologies are developed to aid the workers in manufacturing. This brings the dimension of virtualization. Technologies like augmented reality and virtual reality can help workers in manufacturing, maintenance, training and guidance. According to Chen (2020) a virtual platform-based software can be used to test and debug application models. These technologies eliminate the need of a physical prototype and provide a virtual prototype; in product development process these virtual prototypes can help to detect flaws and issues.

**Automation:** Automation is one of the integral parts of smart manufacturing. It has been observed that robots can perform tasks with better accuracy than human workers and they do not suffer fatigue. They can be also used to support and assist human workers to complete different manufacturing tasks. So, the technology of collaborative robots (COBOTs) is being used not only in smart manufacturing but also in the dimension of smart working. Frank et al. (2019) keep robots and COBOTs separately as it is being argued that robot is a technology that helps to fully automate the manufacturing process but COBOT is a technology that only supports a human worker in the manufacturing process.

**Traceability:** In smart manufacturing, traceability is necessary to locate different finished and semi-finished parts at a certain point in a manufacturing process. Traceability can be internal and external; internal traceability helps in the adaptation of flexible process lines for modular or flexible manufacturing. This helps to produce different products with reduced setup time and production loss. External traceability refers to the raw materials. It is related to cross-functional integration within an organization. The ERP and other similar radical technologies are vital for the purpose of transportation of raw materials, warehousing, order management, replenishment and distribution. It is only possible through cross-functional access to information and resources.

**Flexibility:** Flexibility is one of the major dimensions of smart manufacturing. Additive manufacturing (AM) is a type of a technology which can be used to manufacture different products by using raw materials and resources. According to Frank et al. (2019) AM is a way of sustainable manufacturing, however, mass production is not feasible yet due to longer and slow production process. Weller et al. (2015) aver that AM is a multipurpose technology that has the capability of transforming a digital model into a tangible product. AM provides customization and flexibility as a complimentary feature as this technology does not require additional tools or modifications before the start of production process. The level of flexibility is high as there is no extra cost if production volume is changed during the production process. AM also provides complexity without any additional costs as it is easy to produce multiple variants of products.

**Energy Management**: Energy management is one of the last dimensions pointed out in the present literature. It involves energy monitoring and energy efficiency. One of the aims of smart manufacturing is to monitor energy consumption so that it can be reduced to the optimal level and to increase energy efficiency in order to use resources effectively. Medojevic et al. (2018) argue that new technologies can be used to manage the consumption of energy specifically in the factories. It will help to reduce the maintenance cost of energy and increase the efficacy and reliability. For this purpose, energy consumption data can be collected through smart devices to monitor the consumption. Smart grids can be installed to reduce the energy consumption during the off days of production by devising an energy consumption schedule. It can be developed via cross-functional integration through ERP, BDA and IoT.

### 2.1.4 Categorization of baseline Industry 4.0 Enablers

An assessment has been done by Culot et al. (2020) and Karnik et al. (2022) to define these technologies in detail. A four-quadrant matrix has been developed based on the usage of the Industry 4.0 enabling technologies which can be seen in figure 2.

**1. Physical-Digital Interface Technologies:** A high amount of hardware components and high network connectivity is being used to connect cyberspace with machines, people and products at a given workplace. It involves a cyber-physical system based on technologies like internet of things, augmented reality and virtual reality.

**2. Network Technologies:** High amount of software are being used for network connectivity in order to perform organizational functions online. Network technologies include cloud computing, interoperability, cyber-security and block chain.

**3. Data Processing Technologies:** High amount of software but low connectivity is required in order to analyse data which can help organizations to make decisions based on information-oriented input. Technologies that involve modelling and simulation are best suited here. It includes digital twin, machine learning, artificial intelligence and big data. Normally data processing technologies perform their functions locally but now they are performing their function through cloud computing platforms.

**4. Physical-Digital Process Technologies:** High amount of hardware components and low network connectivity is being used for manufacturing purposes. The technologies include 3D printing and robotics. Culot et al. (2020) have avowed that there are some other technologies that are being mentioned seldom in the literature. It includes energy management solutions; however, it has been used more often recently along with digital technologies.

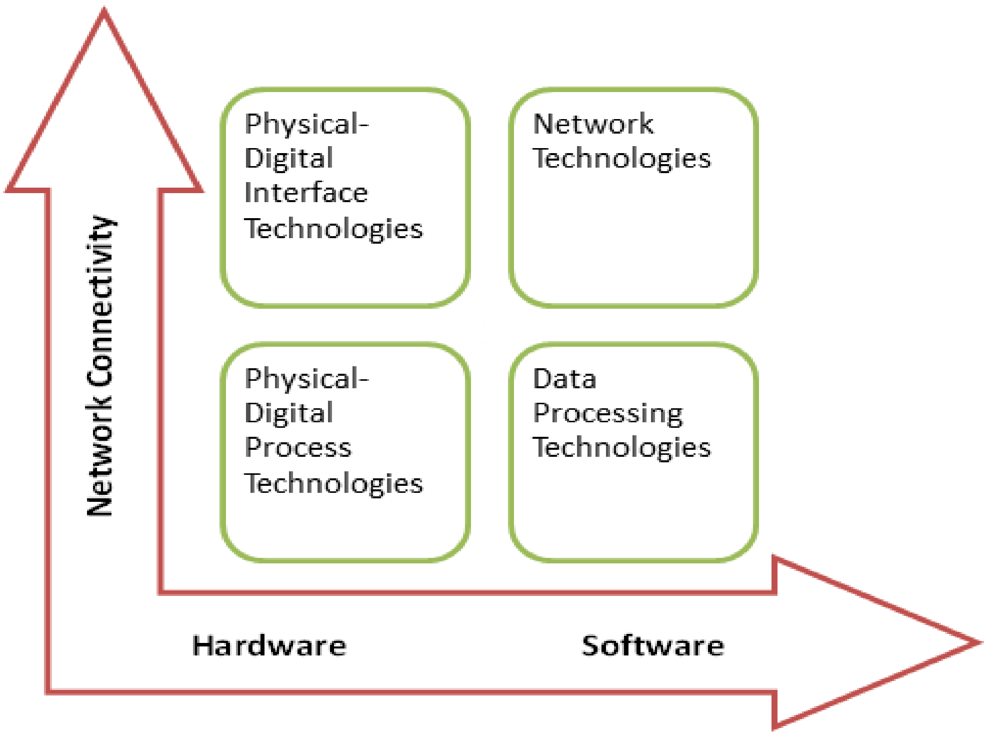


Figure 2 Baseline Enabling Technologies Matrix

Source: Ejaz, (2022)

In manufacturing, Industry 4.0's success lies in the secret of industrial integration and interoperability of technologies. According to Xu (2020) industrial integration is a blend between industrial process and technology. Industries are getting more interconnected in the process of industrial integration. One the other hand, interoperability is an ability of organizations and humans to connect through IoT and CPS. Kumar et al. (2021) argue that industries are implementing Industry 4.0 which is based on the concept of interlinked network of real objects and information known as CPS. Castelo-Branco et al. (2019) state that interoperability can be seen from the perspective of CPS or from a broader perspective of production network vis-à-vis horizontal or vertical integration. According to Sony & Naik (2019) lack of interoperability can cause failure in the implementation of Industry 4.0 technologies. Abdirad et al. (2020) assert that Industry 4.0 focuses on mobility and integration in real time. These technologies are networked with each other both vertically and horizontally. According to Bai et al. (2020) Industry 4.0 technologies integrates manufacturing operations with communication, information and intelligent technologies. Buchi et al. (2020) has sorted out ten main technologies from present literature that they claim to be ten pillars of industry 4.0. From these ten pillars, first nine pillars are technologies that are currently available and explored in the present literature also but the tenth pillar describes new and emerging technologies that also help to reduce industrial waste and optimize performance. Yuksel (2020) has also mentioned the same nine technologies as Buchi et al. (2020) as fundamental technologies. However, this study has renamed one of the technologies from vertical and horizontal integration to ERP. The reason behind this is that organizations use technologies like ERP and other similar technologies for the purpose of vertical and horizontal integration. These technologies are normally examined separately in the literature but in fact these technologies are interconnected with each other. A technology itself cannot offer a ready-made solution to the organizational and manufacturing problems. Some non-technological enablers are required within an organization in order to support and then subsequently implement Industry 4.0 technologies in an organization. These non-technological enablers of Industry 4.0 include *new business/manufacturing models* and *organizational models*. Any major economic or manufacturing gains are not likely possible unless business processes and work processes conjoined with technology being implemented in any given organization.

Since Industry 4.0 is a combination of technologies, these technologies possess different characteristics that make them distinctive and unique. These distinctive features are based on the designs and functionalities of these technologies. Culot et al. (2020) claim that these features stand out as fundamental features after the review of the literature. It includes *Process Integration, Transparent Real-Time Information, Autonomy* and *Virtually Represented Real World*. Process Integration suggests the combination of data of products and manufacturing processes within and across organizational boundaries in order to develop solutions to operational problems. High network connectivity always ensure data gathering from machines and other sources which can help to create a setup like physical-digital interface technologies. This setup will help to perform functions like transparent real-time information and virtually represented real world by creating a cyber-physical space. In a manufacturing process, autonomy means that workers are independent to make decisions on their own and devise solutions to the problems arise in the manufacturing system. It also involves changes in control mechanisms of a manufacturing stem and changes in the organizational structure. Artificial intelligence is mainly used for manufacturing specific and organizational specific decision-making process.

Table 1 Industry 4.0 Enabling Technologies

Source: Ejaz, (2022)

| Sr. No. | Name of Technology | Description |
|---|---|---|
| 1 | Collaborative Robotics (COBOTs) | A collaborative robot or cobot is a kind of a robot that is intended to work and interact alongside humans at a workplace. According to Schmidbauer et al. (2020) they are being created to fill in the gap between manual production and fully automated production line. Cobots are considered as a key technological enabler towards the goal of smart manufacturing. |
| 2 | Augmented Reality (AR) | Augmented reality is a technology that overlays digital data and images on the physical world. According to Porter et al. (2017) AR devices are being used factory workers for manufacturing purposes. The key features of AR are visualization and human interaction. In manufacturing AR can help organizations to reduce errors to minimize downtime and to improve production efficiency. |
| 3 | Internet of Things (IoT) | Duan & Da Xu (2021) state that IoT is a data collection technology embedded with sensors, actuators and software to collect and network data to various devices and components. Internet of things is a system of interconnected computer devices that can be used in our everyday life and for manufacturing purposes as well. According to Xu et al. (2020) due to its increasing importance worldwide, it is now known as Industrial IoT. The concept of a smart factory depends on it as it connects computing devices and sensors together for transmission of data. It improves production in terms of less industrial waste and product quality. Khan & Javaid (2021) argue that IoT provides smart monitoring of the complete manufacturing system. It can be implemented easily in robotics, production machinery, logistics management, security etc. |
| 4 | Big Data Analytics (BDA) | Big Data Analytics is a technology that is used to analyse structured, semi-structured and un-structured big data. The sizes of these datasets can vary from terabytes to even zettabytes. According to Bag et al. (2021) Big data has proven its importance in different fields of operations such as forecasting, inventory management, sales, supply chain management and risk analysis. According to Majeed et al. (2021) Big Data has a substantial impact on smart manufacturing which can help to achieve sustainable, productive and profitable manufacturing. Javaid et al. (2021) claim that Big data is significant to Industry 4.0 as it is used to collect data from within the system. Duan & Da Xu (2021) state that big data is an umbrella term for any technology to manage their data better and it covers all aspects including data capture, storage, networking, computing and analytics. |
| 5 | Cloud Computing (CC) | Cloud Computing is a service of delivering different resources. These resources include different tools and applications such as databases, data servers, data storage, networking and other software applications. According to Duan & Da Xu (2021) CC is related to data storage and computing. Ooi et al. (2018) states that cloud computing can help to change traditional manufacturing models completely through innovation. It is argued that CC can lead to the advent of Cloud Manufacturing (CM) due to its increasing importance and benefits. |
| 6 | Cyber Security (CS) | Cyber security is a system for securing computing devices which includes computers, mobile devices, servers and network systems from malicious attacks and viruses. According to Zarreh et al. (2019) one of the major challenge faced by cyber security in manufacturing is to define a security policy to prevent losses in production and subsequently recovery of the losses. Wells et al. (2014) posit that there is a need to overcome weaknesses present in manufacturing systems to avoid cyber-attacks. One of the major concerns of manufacturing system is the theft of intellectual property which should be secured through encrypted software. |
| 7 | Additive Manufacturing (AM) | According to Bai et al. (2020) it is manufacturing technology that created 3D solid objects by using a series of additive development framework. It is a computer managed machine that produces three dimensional products upon depositing raw material in it. According to D’Aveni (2018) it is incredibly competitive tool which can be used to acquire market leadership as it can be used in any industry. In |

| | | |
|---|---|---|
| | | manufacturing AM can be used for several business models like mass customization, mass variety, mass segmentation, mass modularization, mass complexity and mass standardization. |
| 8 | Simulation | Simulation is a technique that offers a multiple Industry 4.0 related scenarios in order to plan develop and explore different models and solve manufacturing related problems. According to Ferreira et al. (2020) it is an Industry 4.0 enabling technology used to manage multifaceted systems. It is widely used in industrial engineering, operations and supply chain management. In manufacturing systems, simulation provides a set of technologies for the purpose of experimentation and validation of different products, systems, processes and helps in prediction of system performance. It also helps in decision making, training and supports to reduce costs and production cycles. |
| 9 | Enterprise Resource Planning (ERP) | ERP is a process that is used by organizations to manage and connect different part of the business together. According to Rojko (2017) ERP is necessary for flawless networked connectivity between manufacturing and managerial processes. It is an important IT support tool which is being used in business processes integrated with production processes. It includes supply chain, sales, distribution, accounting, human resource, production planning, reporting, tracking, performance analysis, maintenance, resource allocation and other similar tasks. |
| 10 | Other Enabling Technologies | It includes other technologies which are not being discussed more often in the literature but are being used to reduce carbon emission to achieve the goal of lean and green manufacturing. According to Duan & Da Xu (2021) some emerging enabling technologies are 5G Network, Block chain, Deep Learning and Quantum Computing. According to Gorkhali & Chowdhury (2022) Block chain is simply a network of data nodes that are connected through links and operated autonomously. However, Sigov et al. (2022) argue that 6G Network, Artificial Intelligence (AI) and Quantum Computing are emerging technologies. |

There are some features of Industry 4.0 technologies which are not to be found frequently in the literature. These include *predictability, modularity* and *re-configurability*. Predictability refers to the technologies that are being used for supply and demand forecasting and predictive maintenance. The technologies used for this purpose include big data and digital twin. Features like modularity and re-configurability are referred to multiple and changeable configuration of organizational processes including manufacturing processes. It also includes reconfigurable products for dynamic consumer preferences. The technologies required here include programmable machines like robotics.

When Industry 4.0 technologies are being implemented in an organization, it is expected that the performance of the organization will improve in terms of *productivity* and *flexibility*. Gorkhali (2022) say that Industry 4.0 offers flexible monitoring and control of the manufacturing process which requires high level of automation integrated with IoT to provide highest performance with transparency and compatibility. It will help organizations to achieve the ultimate goal of mass customization. These expectations are present where demand is increasing and volatile and cost of labour is decreasing. Other performance objectives include *environmental sustainability* in terms of energy saving through reduced emissions. Two other performance objectives which include e*quality* and *lead time* did not receive a lot of attention in the literature according to Culot et al. (2020). However, there are some technologies that can help to achieve this performance objective such as visualization technologies, real time production planning and control technologies.

Some Industry 4.0 enabling technologies have been discussed in the literature in less detail because they were introduced recently such as Block chain. Zhang & Chen (2020) states that Block chain is one of the emerging technologies in the last couple of years. It is a fundamental technology for decentralization, openness, integrity, security, independence, anonymity and authenticity for diversified technologies. Gorkhali (2022) argue that integration of IoT, BDA with Block chain can provide high level of automation, industrial integration and industrial information integration. Similarly, some technologies have less interdependency level with internet of things such as 3D printing and robotics but they have strong connection with modularization and re-configuration. Hence, there are some ambiguities present in the literature in terms of definitions of Industry 4.0 enabling technologies. There are some challenges in the shape of multi-dimensional concepts like *Lean Manufacturing* and *Toyota Production System* that somehow overlaps the concept of

Industry 4.0. However, the concept of Industry 4.0 is multi-dimensional in its nature and provides opportunities to explore new horizons in the field of manufacturing.

### 2.1.5 Degree of Readiness of Industry 4.0 Technologies

According to Lucato et al. (2019) it is possible to provide a readiness model in the scientific literature. Readiness is a willingness or state of preparedness to do something. This study presents a conceptual approach to measure the degree of readiness Industry 4.0 technologies in a manufacturing organization. It can be theorized that an organization fulfils all the prerequisites required for the implementation of Industry 4.0 technologies. According to Genest et al. (2020) attaining readiness is the first and most important task in order to implement Industry 4.0 technologies. Degree of readiness is defined as a state of full preparedness for a task. So, in the context of Industry 4.0 technologies, attaining readiness means fulfilling all the perquisites necessary for the implementation of Industry 4.0 technologies. Sony & Aithal (2020) and Hizam-Hanafiah et al. (2020) claim that implementation of Industry 4.0 should be taken as a management tool so that it can be reconfigured and realigned according to the capabilities and readiness of the organization. In other words, Industry 4.0 is an interplay of enabling technologies. These prerequisites have primary importance as the success of Industry 4.0 technologies depends on it. Genest et al. (2020) argue that failure in fulfilling perquisites can result in the failure in the implementation of Industry 4.0 technologies.

Literature has revealed that there are two schools of thoughts when it comes to prerequisites. One is the technology-oriented prerequisites and second is the business practices-oriented prerequisites. Technology oriented prerequisites are required before the implementation of enabling technologies of Industry 4.0. As this paper has already established based on present literature that there are in total ten main technology enablers and from them nine are core technology enablers. Prerequisites for some already mentioned technology enablers are elaborated by Genest et al., (2020); however, the study has developed remaining prerequisites. All these perquisites are given in table no. 2. There are in total forty-five prerequisites that have been laid out for Industry 4.0 technology enablers which will help to evaluate the degree of readiness of Industry 4.0.

Genest et al. (2020) and Raunch et al. (2019) have formulated prerequisites from business practices perspective that are necessary before the implementation of Industry 4.0

technologies. Initially, these prerequisites were determined for small and medium manufacturing organizations. However, there is no evidence in the literature that suggests that these prerequisites cannot be used for large manufacturing companies. So, it is assumed that these prerequisites can also been used for large scale manufacturing companies. These prerequisites are mass customization and agility in manufacturing, real-time data integration, implementation of advanced manufacturing, easy usability and economic affordability and organizational culture. According to Genest et al. (2020) there are some studies that suggest lean manufacturing principles as prerequisites to the implementation of smart manufacturing. It is being observed in the literature that organizations having implemented lean manufacturing already are more likely to adopt industry 4.0 technologies. Hence, it can be concluded that positive business practices do affect organizations in order to implement smart manufacturing technologies.

Table 2 List of Prerequisites of Industry 4.0 Technology Enablers

Source: Ejaz, (2022)

| **Collaborative Robotics (COBOTs)** | **Additive Manufacturing (AM)** |
|---|---|
| • Professionally & psychologically trained workforce<br>• Awareness of limitations<br>• Financial capacity<br>• Knowledge of manufacturing SOPs<br>• Manufacturing process & assembly line mapping | • Evaluation of produced products features.<br>• Technical capabilities<br>• Adequate manufacturing time<br>• Security against cyber attacks<br>• Skilled workforce<br>• Required data scanned in 3D format |
| **Augmented Reality (AR)** | **Simulation** |
| • Planning & organizing of data to be shared.<br>• Scanning/uploading of required data.<br>• Suitable software of AR hardware<br>• Thorough mapping of operational processes<br>• Suitable operator's work environment<br>• Study of operator's job functions | • Installed certified hardware.<br>• Interactive software for production ordering & scheduling capacity<br>• High speed internet connection<br>• Financial capacity<br>Trained workforce |
| **Internet of Things (IoT)** | **Enterprise Resource Planning (ERP)** |
| • Experience with RFIDs<br>• Usage of electronic product code<br>• High speed internet & networking<br>• Machine to machine communications<br>• Security system for cyber attacks<br>• System should be able to perform tasks on the fly | • Skilled workforce<br>• Availability of real time data & monitoring<br>• Architecture development<br>• Certified cloud servers for vertical & horizontal communication<br>• Adequate budget |
| **Big Data Analytics (BDA)** | |
| • Data already organized & maintained in digital systems.<br>• Networking system for handling large traffic of data.<br>• Skilled workforce to collect & organize data.<br>• Data protection system<br>• Applications of BDA at strategic level<br>• System should solve problems with available data by itself | |
| **Cloud Computing (CC)** | |
| • Firewall for data security<br>• Qualified workforce<br>• Culture of data privacy at external servers<br>• Integration of systems for interoperability<br>• Financial resources<br>• High speed internet networking | |
| **Cyber Security (CS)** | |
| • Adequate hardware & software tools<br>• Skilled workforce<br>• Data encryption system<br>• Data backup & data recovery setup<br>• Physical & network security | |

### 2.1.6 Digital Transformation

The notion of digital transformation came from the concept of digitalization. Annarelli et al. (2021, p.01) define digitalization as "use of digital technologies to create a business model, revenue streams and value producing opportunities". Savić (2019) states that digitization and digitalization are used interchangeably as they are similar terms and term digital transformation is also being confused up to some extent. According to Saarikko et al. (2020) one must be able to differentiate between digitization, digitalization and digital transformation because they are not the same in terms of scale and scope. Digitization is purely a technical process where old technology is being replaced by new technology. For example, in music industry old record discs are replaced by CDs/DVDs and record player is being replaced by MP3 player. Now technology has shifted to online music streaming. On the other hand, digitalization is a socio-technical process where digital products are being inducted in the organizations as new commercial offerings, new operational procedures and new business models. It is a system of technologies that justifies its existence by benefiting society through technology. Taking the same example from music industry, products like iTunes and Spotify have totally redefined the way people listen to the music.

The concept of Industry 4.0 is based on the proposition that digitalization will set off a technological breakthrough that will lead to the fourth industrial revolution (Haipeter, 2020). According to Cohen et al., (2019) Industry 4.0 offers solutions to the manufacturing industry regarding their mounting digitalization necessities. The ultimate goal of Industry 4.0 implementation in the manufacturing sector is digitalization and servitization. Digitalization from technological perspective means data availability, accessibility, interoperability, connectivity, communication, computation and storage (Liu et al., 2021). Digitalization goes hand in hand with Industry 4.0 as Industry 4.0 provides a holistic purview while digitalization through Industry 4.0 enabled technologies is the radical technological change in the manufacturing sector. It can be formulated that Industry 4. Technologies act an enabler for digitalization in the manufacturing sector.

According to Savić (2019) digital transformation means doing things differently and developing a new business model with the help of modern technologies. Digital transformation is more like a socio-cultural process where organizations adopt digital technologies because change is inevitable especially after restructuring the business models. Matarazzo et al. (2021, p.643) have defined digital transformation as "a process that restructures economies, institutions and society at the system level". Saarikko et al. (2020, p.829) have defined digital transformation as "a process that aims to improve an entity by triggering significant changes to its properties through combination of information, computing, communication and connectivity technologies".

In fig 3, it can be observed that digital transformation is laid out in three different phases. Verhoef et al. (2021) not only explain phases of digital transformation in the light of literature but their study also shed light to the drivers and prerequisites of digital transformation that are imperative for an organization in order to implement digital transformation. Drivers that trigger digital transformation include digital technologies, competition and low OEE. On the other hand, prerequisites are digital resources, organizational structure, growth strategy and performance indicators. Li & Yang (2021) also insist that digital transformation requires comprehensive reforms in the organizational structure and work processes in an organization especially where digital transformation and business model is closely connected.

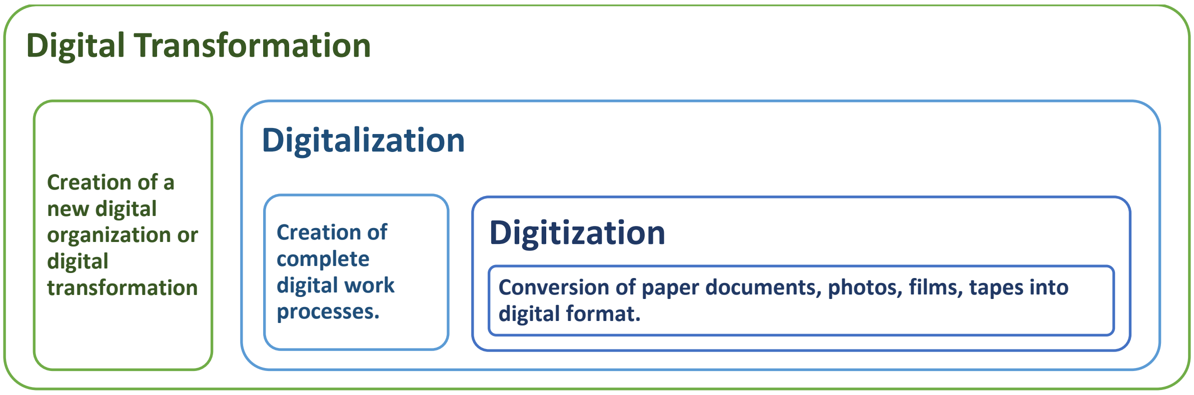


*Figure 3: Phases of Digital Transformation*

*Sources: (Saarikko et al. 2020) & (Savić 2019)*

In this regard, Pisano (2015) has formulated an *Innovation Landscape Map* which focuses on the decision that how much should be invested in digital technologies and how much should be invested on business models. Fours possible outcomes are laid out in this matrix which is as follows. *1- Routine Innovation* where an organization builds its competencies based on existing technological competencies and on existing business model, such as updated versions of Apple iPhones and Microsoft Windows. *2- Disruptive Innovation* where a new business model is required but not necessarily as a result of a digital technological breakthrough, such as Google's Android potentially disrupts companies like Apple and Microsoft. *3- Radical Innovation* which is quite opposite to disruptive innovation, such as for many years' pharmaceutical companies were using chemicals to develop drugs but after the emergence of genetic engineering and biotechnology; business model has been shifted and now drugs are being manufactured in a completely different way. *4- Architectural Innovation* where digital technologies and a business model are disrupted together, such as if Kodak digitally transforms itself, means new competencies have to be learned and mastered. Upon asked "which one is the best?" Pisano, (2015) explained that there is a no magic formula and it is totally company specific. Every organization has to analyse their own potential and other variable factors before making the decision. This study believes that Architectural Innovation can be best suited for manufacturing organizations for digital transformation purposes. No doubt it is a challenging option but it also gives an organization enough space to explore and customize what is best suited for them. In the long run, this will help to make more profits with higher operational performance because foundations of the digital transformation would be tailored and best fit for any given organization.

Digital transformation is a broad concept and it has its own implications upon implementation. Specifically change in the traditional business model is inevitable when digital technologies are being introduced. Organizations may face challenges and berries upon the implementation of digital technologies and digital business models. It is better if organizations start digital transformation gradually and in phases. With the passage of time, eventually organizations will adopt digital transformation as a whole and will adopt a digital business model as well in the process. The process of digital transformation in phases also helps organizations to complete requisites that are imperative for digital transformation. Moreover, Kopp et al., (2019) also argue that Industry 4.0 is a concept that summarizes modern trends like automation, digitalization and data exchange in the manufacturing sector. Industry 4.0 is also considered to be connected with the Work 4.0 as an enabler for digital transformation for people centred new work designs. There is no doubt that digital transformation disrupts the present structure and work ethics. Industry 4.0 is an Architectural Innovation in an organization that brings digital transformation based on Industry 4.0 enabling technologies. This is one reason why it is called fourth industrial revolution.

Acs et al. (2021) advocate about the evolution of a digital entrepreneurial ecosystem based on a digital platform which comprises of users, agents, infrastructure and institutions and this digital platform is an outcome of digital transformation. However, Genzorova et al., (2019) argue that digital transformation is not just connected to platforms and other factors. It is mainly connected with the change of behaviours and organizational structures. According to a survey conducted by American global manufacturing services company; 74% companies consider cultural and organizational structure changes as a major challenge while remaining 26% companies consider technological changes as a major challenge for them. According to Chinoracky et al. (2021) digital transformation is not just implementation of digital technologies; it is an organizational culture and business model shift. Changes in the organizational culture mainly include adoption of new technologies with ease and convenience so that work processes may become easier and efficient.

### 2.1.7 Role of CDOs in Digital Transformation

Bilgeri et al. (2017) propose the induction of Chief Digital Officer (CDO) in the large scale organizations to deal with all the structural changes within the organization caused by digital transformation. In one example, when stock price of Starbucks took a nosedive during the financial crises of 2009, the company hired a CDO to transform their organization digitally. In later years, free Wi-Fi and free digital content was introduced at Starbucks stores. Mobile phone payment system, operations and customer interaction through social media was introduced in the company. The new payment system helped to execute millions of transactions every week and innovated new business model helped to boost the performance.

Singh et al. (2020) state that organizations appoint CDOs to initiate digital transformation within the organization and manage over all structural changes across the organization. The first ever CDO was hired by MTV networks in 2005 and since then demand of CDOs has been increasing among C-level executives. Initially, the need for CDO in retail and manufacturing sector was not seen that vital. However, in the recent years companies like L'Oreal, Nike and Novartis have appointed their respective CDOs to follow this trend (Firk et al., 2021).

On the other hand, Venkatakrishnaiah & Ramanathan, (2019) elaborate "how" a CDO implements digital transformation. A CDO needs to develop a service oriented architecture as a foundation to start the journey of digital transformation in an organization. It will connect all the channels of the organization through networking, data analytics and machine learning. It will help an organization to develop an endless operational support among customers, suppliers and employees. It will help CDOs to strategize accordingly based on the real time data and analytics collected through technological tools. This is the point when CDO lays the foundation of digital platform which is going to play a vital role in the digital transformation.

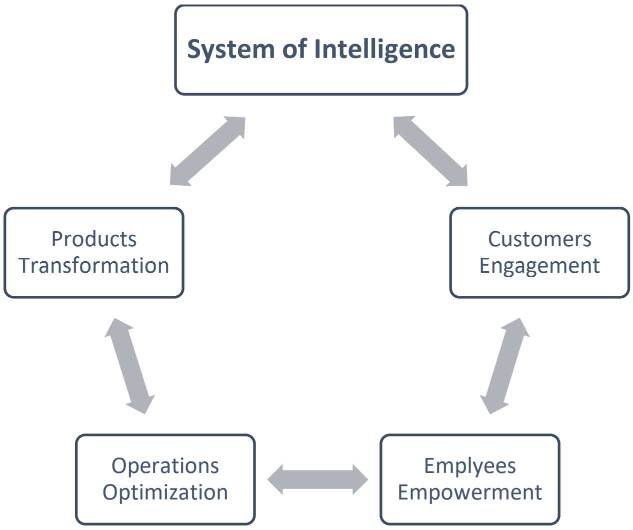


Figure 4: System of Intelligence as an enabler of Digital Transformation

*Source: (Venkatakrishnaiah & Ramanathan, 2019)*

In fig.4 a service oriented architecture has been laid out which will act as a guiding principle for a CDO to implement digital organization in an organization by taking all the relevant stakeholders on board. The concept of Industry 4.0 is a multidisciplinary phenomenon and the relevant scientific literature is available in several disciplines like engineering, computer science etc. This study focuses on scientific literature in the context of management sciences so that literature review should be relevant at possible. It is imperative to explore existing scientific literature so that future research should be able to contribute and add value to the existing literature.

## 2.2 Overall Equipment Effectiveness (OEE)

Manufacturing companies are required to enhance productivity within their manufacturing facilities. The goal of competitiveness can be achieved via continuous and innovative growth, high quality products and short lead times. In a manufacturing environment, competitiveness can be affected due to unskilled operators, stoppages and defects in quality of products. So in order to remain competitive organizations should keep performance indicators like speed, cost, flexibility and quality in terms of manufacturing performance. OEE can be used to track the machine performance in any production facility as it is easy to calculate. The concept of overall equipment efficiency was originated in 1971 however; OEE was initially used by Seiichi Nakajima in the 1980s as a quantitative metric for measuring productivity for individual equipment in the manufacturing environment (Bhade & Hegde, 2020). OEE is known for maintenance and a as a tool for the measurement of machine effectiveness. According to Lanke et al., (2016) machine with a lower OEE means that there is a bottleneck and it also lowers the reliability of the machine. The equipment reliability is one of the key factors in the production loss and consequently loss of competitiveness. So it is crucial to make sure equipment is reliable as it will lead to the manufacturing competitiveness.

OEE is defined as “available valuable time for operation over loading time” (Yazdi et al., 2018). Operation time can be interpreted as the time used for the production of satisfactory products while loading time is refer to the time needed for an equipment to run through a given period of time. OEE is a tool that can help manufacturing companies to measure their productivity losses and help them to apply resources to improve the productivity. OEE consists of three factors called availability, performance and quality. Lakho et al., (2020) also argue that OEE is a method to gauge performance and efficiency of the machinery by using the factors of availability, performance and quality. According to Yazdi et al., (2018) OEE is a standard that has to be used to evaluate machine performance on the bases of required data. In this regard, Industry 4.0 enabling technologies can be utilized to obtain real time data from the equipment so that overall effectiveness of the machines can be calculated. The data will help to evaluate the performance and OEE score of the manufacturing firm in question.

In the Industry 4.0 context, digitalization of the production process and data collection is of prime importance. It is vital to measure the equipment productivity within the manufacturing system. OEE was introduced by Nakajima as a metric to measure equipment productivity in a manufacturing system (Ng Corrales et al., 2020). OEE provides a productivity ratio between the factual manufacturing and what could be manufactured ideally. OEE measures six losses in a manufacturing system based on the aspects of availability, quality and performance. Ng Corrales et al., (2020) have defined i. Availability as “is the machine running or not?” ii. Performance as “how fast is the machine running?” iii. Quality as “how fast products satisfied the requirements?” Availability measures downtime loses like breakdowns, set up times and adjustment times. Performance measures speed losses due to stoppages and reduced speed. Quality measures defect losses due to process defects or reduced yield. OEE applications have been modified over time based on the different industrial needs. It proves insufficiency of OEE as a standard indicator to measure equipment performance in a manufacturing system. So, the OEE applications have to be modified to fit according to industrial needs. In this context, Industry 4.0 enabling technologies can be used to facilitate the OEE applications to reduce the uncertainty in the results.

Industry 4.0 can help manufacturing companies to boost competitiveness and efficiency by interconnection of resources through the enabling technologies (Miragliotta et al., 2018). These resources are data, people and machinery. Data is going to play a crucial role and has the potential of becoming a new paradigm in the OEE process and obtaining competitiveness for a firm in a manufacturing environment. Internet of Things (IoT) is one prominent technology that helps to obtain the required data. This data helps manufacturing companies to evaluate their OEE score. According to Lakho et al., (2020) one study shows that OEE improvement is 13% in the small and medium size firms in the manufacturing sector. There were some limitations to the study as not all lean manufacturing techniques were used in the evaluation of OEE score.

Sandengen et al., (2016) regard Industry 4.0 as an essential driver to implement predictive maintenance to uplift the asset utilization up to 50% by reducing machine downtime. It will help to improve machine life span up to 40%. Sandengen et al., (2016) state that Predictive maintenance is a performance indicator and it is widely associated with the OEE. In this regard, OEE can be implemented as a tool for predictive maintenance using Industry 4.0 to facilitate the process resulting into decrease in downtime up to 50%. It can certainly help manufacturing organizations to improve their OEE score as predictive maintenance will have a certain impact on the availability aspect of OEE. The OEE calculation helps to define improvement actions to be implemented in the production processes and helps to eliminate the existing problems (Aleš et al., 2019). When OEE is being applied with the purpose of predictive maintenance, it can help resolve existing problems resulting into the improvement of the production processes.

According to Aleš et al., (2019) a successful analysis of OEE is inadequate as no equipment in a factory is isolated but work in a complex operates in an interconnected and complex environment. However, OEE is a useful tool to highlight areas of improvement in the production processes; however, it requires involvement from labour to top management to reap the fruitful benefits. One important thing is the interpretation of the OEE data. It is important to detect the critical areas in the production lines that require improvement. Failure in the interpretation results into the decrease in reliability of the machines and OEE score. The use of Industry 4.0 enabling technologies can ensure the operational reliability of the machines if machines are being decentralized in the manufacturing process Aleš et al., (2019). Each machine works as an individual machine in the manufacturing setting. It helps to gain an in depth knowledge of machine efficiencies.

The implementation of IoT makes these individual machines autonomous by collecting large amount of data to be processed further for various purposes. The data can be utilized in the areas of supply chain, energy consumption and for production/maintenance efficiencies. Industry 4.0 is one of the key maintenance and performance indicators in the context of OEE. It helps to collect data in real time and evaluates its effectiveness for the production set up. Sandengen et al., (2016) also argue that IoT do not have a focus on the production, however, its utilization helps to communicate with the machinery. In this way, the data obtained will help in the decision making and the goal of digital predictive maintenance and increasing OEE score can be achieved.

The road to digitalization and Industry 4.0 technologies is the way to implement predictive maintenance into a manufacturing system. The goal of predictive maintenance can be achieved by maintaining a high OEE score (Jantunen et al., 2017). Industry 4.0 enabling technologies like IoT, Big Data and Cloud Computing can help to achieve this goal. According to Agung & Siahaan, (2020) OEE helps to inflate industrial competitiveness by reduction in the failures in the production lines and consequently, reducing operational and maintenance costs. The improvement in the OEE score helps manufacturing facilities or machines to enhance their efficiency hence ensuring their competitiveness in the global market (Moussa & Hartman, 2023). The achievement of OEE score of 85% seems challenging but it is not impossible. Manufacturing firms can employ Industry 4.0 technologies to strive for the optimal OEE score.

It is a challenge for manufacturing companies to remain competitive in the global environment and OEE can help in the potential improvements (Ahmad, 2018; Iannone & Elena, 2013 and Gibbons & Burgess, 2010). In the terms of OEE, manufacturing firms can realize competitive advantage through the elimination of waste and by exploiting core competencies and capabilities. According to Gibbons & Burgess, (2010), A sustainable competitive advantage can be harnessed through the better resource utilization and optimizing OEE. The competitiveness of manufacturing firms is based on the availability and the availability of their production facilities (Molina-Barrientos et al., 2021). When a manufacturing facility is unable to continue the production, the elimination of bottlenecks and downtimes due to stoppages are done by the companies. The metric used to enhance performance is OEE as it is been declared as a primary method to measure equipment performance (Molina-Barrientos et al., 2021).

While OEE being a popular method for the measurement of equipment performance and yet it has some limitations also which makes it hard to record accurate results. The integration of equipment in the manufacturing facility is necessary to overcome this OEE weakness. Although OEE is one popular metric to measure the equipment efficiency in the manufacturing environment but OEE also has some limitations. OEE mainly considers equipment efficiency but does not consider other factors that can affect the equipment efficiency such as material flow, worker output or process improvements (Moussa & Hartman, 2023). There are other external factors that OEE fails to comprehend in the complex environment of the manufacturing facility. These include demand variability, supply chain disruptions or market fluctuations as they can impact on the machine efficiency and OEE may not be able to provide accurate reading on these external factors.

Ahmed, (2013) argues that there are several factors that can affect OEE matric in the production process. These factors might not be considered in OEE calculations as well as they are neglected at times. In availability, the downtime is responsible for production loss and there can be several reasons for unplanned downtimes. For example when machine stops due to unavailability of parts as it means no inventory, it is a supply chain problem. In one another example, of one machine supplies parts for the other and it shuts down, it will halt the whole production line. So safety stock should be added to avoid these kinds of issues. Similarly, changeover is another example of unplanned downtime due to lack of tools that help to reduce or eliminate setup and changeover times. In the performance metric, issues are hidden and overlap with availability matric as well. Slow speed of machines result into low output causing speed loss.  Speed loss is often caused by poor maintenance however; factors which are often neglected by the manufacturers are machine operator skills, training and ability to follow instructions (Ahmed, 2013). In the quality matric, it is easy to detect defective products when they are being produced but what is not that easy is the identification of the source causing quality variations.

## 2.3 Competitiveness & Industry 4.0

Competitiveness is defined as "competitiveness refers to the capacity to engage in the competition whether capacity is fully realized or not" (Sum & Jessop 2012, p. 27). Normally competition occurs in stratified environment rather than at a level playing field. It is so because different markets set different parameters of competition. The most important market will set the most dominant competitive force. Competitiveness is also defined as "a set of institutions, polices and factors combined to determine the level of productivity of an economy and its capacity to generate wealth, returns on investment and determining potential for economic growth" (Farinha et al. 2014, p. 261). Carayannis & Wang (2011) describe two types of competitiveness. One is resource based competitiveness where higher productivity is achieved through lower cost of natural resources. Second is innovation based competitiveness where higher productivity is achieved through higher efficiency and technology.

In developed economies where competition get intense; "push and pull model" is used by organizations to achieve competitiveness. In this model "technology push" forces an organization to adopt smart technologies for higher production efficiency and "market pull" is the market demand which also forces an organization to adopt smart technologies for higher production efficiency. However, in the less developed economies or regions; according to Farinha et al. (2014) efforts to develop knowledge infrastructure are being made to attract medium to high tech industries to boost competitiveness. The key to attract medium to high tech manufacturing is innovation and innovation comes from the collaboration between academia and industry. Knowledge management can play a crucial role in influencing competitiveness as academia can provide essential knowledge to industry and promote economic growth. Later on, government can also play its part by making supportive policies which can help to boost innovation and deliver technology driven competitiveness. According to Carayannis et al. (2021b) these three helices provide the comprehension of the social reproduction of the dynamics of innovation. Industry 4.0 technologies can help to gain competitiveness as it has the capacity to enhance the manufacturing process and meet global demands.

The swift strides in the development of world's economy have empowered organizations to produce more efficiently and in large quantity. This has allowed organizations to reduce the costs that led to the development of competition in the consumer market. Consumer markets have been the foundation of the global economy since the industrial revolution. This has brought economic, environmental, and social challenges for the present and future generations. To meet the consumer demand, companies aim to shorten product lifecycles. However, it is an essential consequence of this that the lifespan of products is constantly decreasing, thus encouraging re-purchase. This has led to the development of the so-called linear consumption model (Bradley et al. 2018; Kambanou & Sakao 2020).

### 2.3.1`Quintuple Helix Model and Sustainable Competitiveness: An Analytical Framework

Ivanova, (2014) state that the concept of Triple Helix originated in 1990s, however a similar concept was under usage at the time of Great Depression during 1930s. Although that time this concept was not formally conceptualized and detailed mechanism was not laid out. The academia has outlined the innovation system within the domain of knowledge management as Triple Helix Model. There is no common definition of innovation agreed upon in the academia. However, Planing (2017, p. 3) provides a simplified form of the definition of innovation which is “Innovation = Idea + Invention/Realization + Exploitation”. According to Carayannis et al. (2019) the concept of innovation system is built on the double helix model which is an interplay between academia and industry. Later on, government as third helix was added and it became Triple Helix model. According to (Leydesdorff 2011) the Triple Helix Model was proposed by Etzkowitz & Leydesdorff which incorporates relationship among university, government and industry in order to explain structural changes in the knowledge economy. In contrast with political economy, in knowledge economy the structure of society is constantly challenged by transformations that originated from digital technologies. Traditionally, Triple Helix Model of innovation is focused on the cooperation among academia, industry and government. Momeni et al. (2019) state that the purpose of Triple Helix model is to create and explore new knowledge, technology, product and services. It is claimed by Carayannis et al. (2019) that Triple Helix model will remain in the endless transition. The fourth helix of civil society was added into Triple Helix to create Quadruple Helix. Civil society can be a non-governmental organization or informal institutions that can play a part in innovative activities.

Dhewanto et al. (2020) state that a body of researchers researched and explored different dimensions of innovation and other factors that play a role in the process of innovation for over 30 years before creating the Quadruple Helix model of innovation. Grundel & Dahlström, (2016) say that Quadruple Helix model broadens the concept of innovation. It represents not only political and civil rights but also sustainable development. According to Carayannis & Campbell (2021a) Elias G. Carayannis and David F.J. Campbell are the co-creators of Quadruple and Quintuple Helix model of innovation. Quadruple Helix brings new dimensions about society and civil rights. Moreover, Quadruple Helix is not only limited to scientific universities but also to art universities. Carayannis & Campbell (2014a) argue that Quadruple Helix is human centred while Triple Helix is institution oriented and focuses on knowledge economy. According to Carayannis & Campbell (2014a) and Casaramona et al., (2015) civil society is based on the attributes of media/culture based civil society, art/artistic research and art based innovation. With the media and culture elements presents in the Quadruple Helix; it represents more composed and strong pursuit of innovation which can be reflective over academia, industry, government and civil society. Carayannis & Rakhmatullin (2014b) assert that quadruple Helix model promotes the concept of smart specialization that integrates four helices in the context of knowledge economy and knowledge production.

According to Carayannis et al. (2019) a fifth dimension is added which is natural environment and Quadruple Helix becomes Quintuple Helix model of innovation. Natural environment is a subsystem of knowledge and it makes Quintuple Helix more comprehensive than its previous version. Carayannis et al. (2012, p. 4) define Quintuple Helix model as "it is interdisciplinary and trans disciplinary at the same time; the complexity of five helix structure require understanding and continuous involvement of the whole disciplinary spectrum, ranging from natural resources to social sciences". Carayannis & Campbell (2021a) argue that Quintuple Helix model is a socio –ecological transition of society, economy and democracy.

It is based on the idea of knowledge production and its application over the society. It creates a synergy among economy, society and democracy. It is also contended by Alhassan et al. (2017) that natural environment has a relationship with the existing four helices as it impacts and shapes the direction of innovation and knowledge activities. According to Kolehmainen et al. (2015) knowledge based development can be quite challenging especially in less economically developed areas. In the case of competitiveness, it can be a difficult but possible.  Carayannis et al. (2021b) argue that knowledge based development which is also known as competitiveness and superiority of knowledge is determined through the capability and capacity to integrate various mode of knowledge through cooperation and competition.

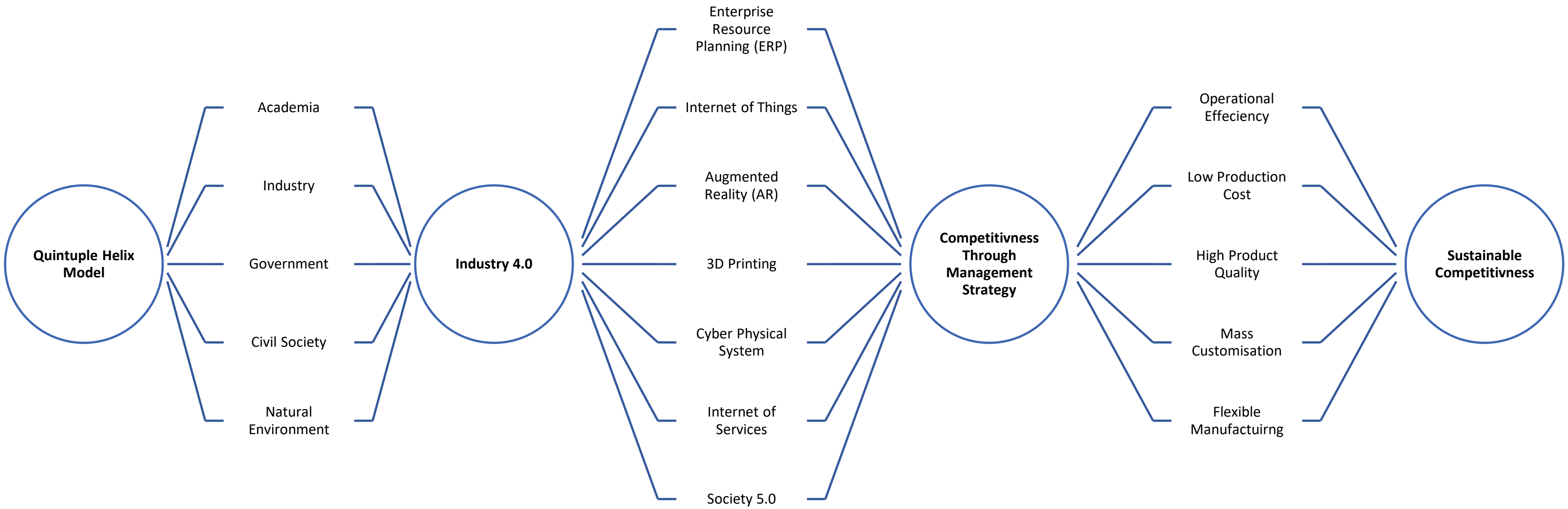


Figure 5: Quintuple Helix and Sustainable Competitiveness Interlinkage: Analytical Framework

*(Source: Author's Own Work)*

### 2.3.2 Components of Competitive Advantage

Now competitiveness is often misunderstood by the mangers when it comes to manufacturing. Enhancing the ability of the workforce of converting input into output is competitiveness. It includes technological advanced tools, trained and motivated workforce and other elements which inhabits the culture of competitiveness in an organization. According to Aranguren and Magro (2020) few decades ago competitiveness might have been a blurry concept but now its importance has been recognized especially at regional level. Reyes and Useche (2019, p. 4) has defined competitiveness as “the capacity of a firm to achieve high levels of productivity over time.”

Competitive advantage is regarded as significant in the success of an organization. Azeem et al. (2021) state that the substance of a competitive advantage is founded on unique and sustainable competitive edge. Competitiveness highly relies on the capabilities and resources. According to resource based theory the way organizations owns and utilizes resources is often related to competitiveness of an organization. Resources are the core component of any organization’s competitive advantage that leads them to the brilliance. Organizational culture, which is the first component of competitive advantage, is being regarded as a core competency to develop competitiveness. Organizational culture is defined as “employees’ shared values, beliefs or perceptions of the organization and its environment” Azeem et al. (2021, p. 1). The second component, knowledge sharing is described as an exchange of knowledge, information, facts, skills and practices within an organization is known as knowledge sharing. Knowledge sharing help organizations to increase their knowledge based resources. It helps organizations to enhance their ability to develop sustainable competitive advantage over their rivals. The third component; Innovation in an organization is a potential indicator of creativity. The implementation of new business practices or technologies is generally known as innovation. Organizational innovation also means adoption if new practices in the workplace to increase performance which can help to create a competitive edge consequently. Innovation can play a particularly important role in the long term to gain competitive advantage.

Competitiveness in a business cannot be obtained without organizational culture, knowledge sharing and organizational innovation. It is a state where an organization performs better than its rival in the market in terms of cost, manufacturing, technology and other various factors. Azeem et al. (2021) posit that an organizational culture affects an organization deeply especially when it comes to the development of competitiveness. Organizational culture reflects employees' attitudes, creativity, quality and productivity which consequently reflect into the employees' performance. Similarly, knowledge sharing is equally important as organizational culture in order to achieve sustainable competitive advantage. Knowledge based assets are important for an organization but alone they cannot offer a performance that can translate into a competitive advantage. Knowledge sharing should spark knowledge based culture within the organization supported by innovation; that would really create a change within an organization and an organization will come to a position to offer a competitive advantage. Bessant & Francis (1999) use the term 'learning organizations' where knowledge sharing is an integral part of the organizational culture. When there is a network of knowledge sharing embedded in an organization; it will not only help in the individual and professional growth of the workforce but also drives innovation within the organization. Especially in the manufacturing organizations where R&D plays an important role in the adoption of new technologies and without the culture of knowledge sharing, a competent workforce to get things done that is needed for competitiveness is not possible. According to Azeem et al. (2021) innovation is a vital component of competitiveness. Innovation is necessary to explore new opportunities in the business and it is essential for organizational progression. Knowledge sharing and organizational innovation can play a decisive role in the organizational culture to bring performance based competitive advantage in an organization. Azeem et al. (2021) argue that empirical data suggests that organizational culture promotes innovation and knowledge sharing within an organization while innovation and knowledge sharing are crucial for an organization to develop competitive advantage.

The next step after identifying components is to prioritize the competitive advantage. An organization should know what kind of a competitive advantage they are looking for. They have to decide what they want. Ocampo et al. (2017) have given seven dimensions of competitive advantage that an organization should prioritize and pursue afterwards. These dimensions include cost/efficiency, flexibility, quality, delivery time, innovation, customer service and environmental protection. Now organizations either pursue one of these or a group of priorities from these given priorities. Researchers are convinced based on their research that organizations cannot pursue all of them at the same time. There is a trade-off exists among these priorities.

### 2.3.3 Competitiveness Through Resources & Capabilities

The management strategy of competing through resources works on the principle of (RBV) resource base view. RBV sees a company as a collection of tangible and intangible assets along with capabilities. Collis & Montgomery (1995) say that RBV is a combination of internal and external standpoints within an organization that helps an organization to assess strengths and weaknesses. According to RBV, no two companies are same even if they are given identical resources because they will always have a different set of skills, organizational culture and work experiences. The competitiveness can be considered as the driver of the firm's performance based on the existing resources as assets or labour based resources. The measurement of a firm's competitiveness is more like an assessment as there is no proper variable available for that purpose (Csapi & Balogh, 2020). According to Lafuente et al., (2020) competitiveness is a multidimensional concept based on resources, capabilities and it is positively linked with the firm's performance.

A list of perquisites have been presented in table 2 by Ejaz, (2022) that acts as not only the tool of measurement of industry 4.0 readiness of a firm but also as the multifaceted drivers of the operational competitiveness based on the Industry 4.0 technologies. These perquisites are the resources and assets that a firm must have to be able to implement Industry 4.0 technologies in order to enhance their operational performance. As far as outcomes or performance assessment of the drivers are concerned, these are primarily focused on the indicators related to manufacturing performance of the firm. In this context, Reduction in the use of resources, Reduction in Cost of Production, Increased Operational/Manufacturing Capabilities, Increased R&D, Increased Product Quality, Increased Product Quality, Increased Mass Customization, Flexible Manufacturing Process and More Flexible Product Design are the performance measures that are being developed after the review of the existing literature that is aligned with the goals of the thesis. These performance measures can help to assess the manufacturing competitiveness of a manufacturing firm.

According to Zahra & Das (1993) an organization's resources fall into mainly two categories. One is tangible and the other is intangible. Tangible resources are in physical shape and they can be seen and observed. Tangible resources are also easy to count with accuracy. While in the case of intangible resources, they are hard to observe as they are normally not in the physical shape or form. Intangible resources include technological, financial and human resources. For instance, a garment manufacturer in Denmark implemented an advanced technology to reduce manufacturing time and to manage the industrial waste. This combination helped the Danish manufacturer to avail the competitive advantage. Zahra & Das (1993) state that intangible resources also include organizational structure, administrative skills and organizational culture. These resources are valuable and crucial for a firm to create a competitive advantage. A survey of executives of British companies reveals four vital intangible resources which are inevitable for a firm to develop a competitive advantage. These resources are company reputation, product reputation, employee expertise and organizational competence.

The competence of an organization comes from their workforce. Competence of employees of a firm is a vital element in the implementation of strategies to achieve strategic goals. The term 'competence' is defined by (Horvat et al. (2019, p. 826) as "learnable abilities of an employee or an organization to combine or exploit different resources in a purposeful manner to do certain tasks individualistically". Another study revealed that manufacturing is an important area of employee expertise. One more study claims that close ties with the suppliers and buyers can help organizations to improve their manufacturing efficacy. All these are the examples of intangible resources that might play a vital role in the achievement of competitive advantage. According to Cao et al. (2021) when a manufacturing firm possess resources that are rare and valuable; only when an organization develops a competitive advantage because rare resource materials are hard to acquire and nearly impossible to imitate.

These resources available in an organization function as a guiding principle to devise and implement strategies in order to attain competitive advantage. The choices an organization make is solely based on the kind of resources available within the organization. For example, a British sports car manufacturer, TVR used an advanced technology to produce customized cars according to the needs of their clientele. This new technology helped TVR to introduce flexible manufacturing with a highly trained workforce. With the effective use of technology, TVR created a competitive edge and that resulted into a high market share as it helped to beat its market competition Lotus in the British market. Zahra & Das (1993) argue that the key behind the competitive edge is uniqueness and un-substitutability of tangible and intangible resources. An organization can develop a competitive edge based on the mix of manufacturing resources. Now scarcity and uneven distribution of resources can create a competitive advantage for a particular company. In other words, organizations can create competitive advantage through manipulation and exploitation of the unequal distribution of the scarce resources.

Smart technologies can help to rejuvenate not only the conventional manufacturing processes but also help in the creation of new product designs. Pisano & Willy, (2012) state that product designers and process engineers sometimes underestimate one another which results into effecting both product and process. Advanced technologies can make product design and manufacturing process interdependent on each other which can help the companies to develop a competitive edge based on their capabilities. Companies should continuously invest in R&D to stay ahead of their competitors because research also indicates that capabilities can erode over time and competitiveness developed on the capabilities also wears down over time.

Sustainable competitiveness is highly dependent on the competence of the employees. How quickly they adapt and learn new changes in terms of organizational structure or implementations of new technologies actually determine the potential of a firm in order to develop a sustainable competitive advantage. According to Horvat et al. (2019) an organization can fulfil their strategic goals to achieve a competitive advantage like flexibility, short production cycles and others only if the employees are competent enough to learn and apply new digital tools in a form of a management strategy to achieve their goals and developing a competitive advantage in the process. An organization must identify its competitive needs first in order to determine what kind of competency is required. Once competitive needs are defined, than the task of analysing marketing and technological needs and setting short and long term strategic goals has to be fulfilled by an organization.

Sometimes organizations opt for competitiveness though clustering and public policy. These are not in the purview of this thesis however, their importance cannot be ignored. So the study has also shed light on these areas to cover the broad aspect of competitiveness.

### 2.3.4 Competitiveness Through Clustering

Evans (2019) has claimed that clusters are extremely important for industrial growth and their importance has been recognized for last 20 years. Clusters always have a positive impact on the productivity growth of the geographically co-located firms. Bettiol et al., (2020) state that now Industry 4.0 has provided a technological platform to form technological based clusters.

Lis (2019) has argued that clusters help organizations to attain competitive edge along with efficiency and innovation. The notion of proximity presented in the literature help organizations to enhance performances and increase cooperation between organizations located in the same vicinity.

Based on research (Lis, 2019) has mentioned five dimensions of the proximity which includes geography, competence, social, organizational and institutional based proximity. So far geographical proximity is the least complicated and the most important dimension of cluster formation. It refers to the physical location of certain economic entities along with their supporting industries in a specific radius of area. Aranguren & Magro (2020) has also emphasized the importance of clusters based on geographical proximity. Akpinar (2020) states that multinational organizations also relocate themselves; sometimes to other countries to avail location based advantages. Location based advantages include suitable market size, favourable government policies, institutional framework, industrial incentives and tax rebates. Akpinar (2020) also says that there are two types of geographical based clusters; natural and man-made, both are crucial for economic growth and competitiveness. Arrona et al. (2020) explain that there are multiple factors on which geographical based clusters are dependent; mostly on policy making. It is believed that it is government's job to design and implement such policies that foster location based industrial clusters. Tahir & Tahir (2019) also argue that either governments or institutions can take initiative to force market players to develop clusters.

Studies indicate that clusters are essential for economic progress, technological readiness, innovation and market regulations and infrastructure. These elements are incredibly important for achieve competitiveness. Porter & Rivkin (2012) also state that foundation of competitiveness is a sophisticated cluster of industrial infrastructure at regional level; supported by business friendly environment and policies. Like Toyota follows *"kaizen"* continuous improvement principle not only for their production facility but also for their workforce and their 12 out of 15 production facilities are located in or around the Toyota City forming a cluster. Toyota's executives believe that the cluster has played an important role in the shaping of Toyota's culture. As Atkin et al. (2017) were researching on the technology adoption barriers in the football industry in Pakistan; they found that cluster has played incredibly significant role in the growth of football manufacturing as they recorded 135 firms located in a small city producing 30 million footballs annually sharing same standardized technology and production processes.

Pisano & Willy (2009) also illustrates the importance of cluster of companies at the same place in the shape of forming common. Common is a place where all the industry related companies work together and by doing so they will have an integrated R&D and other services. It will cultivate the culture of innovation and research in a particular field and all companies in the common share the benefits together. In one example, Novartis has relocated their head office from Switzerland to Boston, US because several research centres were already working in that region in the related field. They can help Novartis to develop new and advanced drugs in the future and most importantly they will develop the capabilities across time which will be difficult to copy for other companies. In another example, US based solar panel manufacturing companies claim that their Chinese competitors enjoy an unfair advantage which is government aid and funding to the industry but Pisano & Willy (2012) reasons that their real competitive edge is that their whole technological infrastructure and electronics industry which is centred in Asia and no amount of government funding can help to overcome what they have developed.

### 2.3.5 Competitiveness Through Public Policy

Competitiveness is nothing like creating new jobs or increasing wages; it is long term productivity along with raising living standards of the people. According to Porter and Rivkin (2012) competitiveness brings prosperity to both companies and citizens. Zahidi (2020) says that competitiveness is not just about growth and productivity; it is about developing policies that can not only ensure sustainable and greener environment but also helps to boost foreign investments. It is the government’s job to develop local manufacturing oriented policies so that foreign investment can be attracted and so does the resources of production. There is no short cut to this approach as developing competitiveness is a process which takes time.

Lall (2004) has formulated two approaches that governments can use to devise policies for industrial competitiveness. These approaches are *neoliberalism* and *structuralism.* Industrialized economies liberalize their industry and free market controls almost everything with nearly zero government intervention. It includes allocation and relocation of resources and industrial assets. In this strategy, government’s job is to provide stable macro-economic conditions and industry normally gives high growth and productivity as an outcome. In this approach markets are efficient and rely on technological competitiveness. In the structuralism approach, government controls almost everything and free market is not entrusted. It is argued that free market played a crucial role in the industrial success of countries in East Asia. Heavy reliance on free market might be a mistake because they are not perfect and government intervention is needed for markets to work efficiently. In structuralism, a government policy is vital for industrial success because there is no reason to follow neoliberalism just because of some failed government policies in the past. In one example, US government has ordered a policy review to prevent auto industry from financial losses in the light of recent supply chain disruption of semiconductors during the pandemic. According to Leary (2021) government is intended to boost domestic manufacturing of critical materials including semiconductors. In this way reliance on foreign suppliers will be reduced and that will help to thwart supply chains disruptions in future. Now this example shows that when free market fails to control the market conditions by itself; then government intervention is necessary to make sure that free market is working efficiently. It is also the job of the government to make policies that encourages manufacturing so that industrial competitiveness can be harnessed. It is a long term strategy. It might not help in short term to resolve the immediate problem of supply chain disruption and raw material shortage but it will help in the future to avoid similar situations to develop in the first place.

According to Sminia et al. (2019) several governments in the world have initiated their working to devise policies based on technology to create competitiveness in manufacturing firms. These policy agendas have started as “La Nouvelle France Industrielle” in France, “Indurtrie 4.0” in Germany, “Rebirth of Japan” in Japan, “Manufacturing 3.0” in South Korea, “High Value Manufacturing” in UK, “EU Factories of the Future” in EU, “Advanced Manufacturing Partnership” in US, “Made in China 2025” in China and “Make in India” in India in different parts of the world to gain competitiveness through Servitization and not through going into price wars with the competitors. Servitization is mainly based on two factors. First is the functionality of the product offering with respect to its efficiency and effectiveness in terms of customer and second is building long term customer relationship through constant interaction. Servitization helps organizations to be competitive based on superior product quality and manufacturing technology and escape from the old ways of competitiveness like price competition and commoditization.

### 2.3.6 How Companies Can Achieve Sustainable Competitiveness?

The real question is how a company can achieve the goal of sustainable competitiveness. Different companies apply different kind of strategies and try to acquire different kind of capabilities over their competitors. Kaplan & Norton (2008) propose a management system integrated with operational strategy which works in a closed loop. It will help companies to avoid breakdowns and failures in their operational plans. In this five steps management system, first step is to develop a strategy. In order to do that a company must analyse and identify their core competencies and then devise a strategy accordingly. Now a company may have developed core competencies based on the resources or capabilities. In case of resources companies must ensure these resources are dependable, durable and sustainable so that they can be used as leverage. Still there are strategic implications in developing a strategy because resource can diminish over time. Collis & Montgomery (1995) argue that resources must be upgraded and invested over the course of time because technologies can change in no time and resources can be threatened. Companies must keep their resources in best possible way so that they can reap the benefits from them. In the case of capabilities, some companies gain capabilities by investing in the building of infrastructure in an unconventional manner that no one has done in the industry. In one example, Wal-Mart developed a cross docking system to replenish their stores even twice a week with their own fleet of trucks and cargo aircrafts. It works on the basis of their own satellite communication system among all the venders and suppliers which made it hard to replicate for K-Mart. In one other example, Honda developed an efficient dealership management system based on MIS tools and training that provides an edge to Honda to excel.

In the second step, once a strategy is developed the next task is to translate it into the workforce as it is important because without it a company cannot harvest the desired culture within the company. Stalk et al. (1992) assert that it also requires training and organizing the workforce in an unconventional manner to develop these capabilities so longer a company can take in developing them, the harder it will be to copy them. Toyota has cultured and developed the strategy of continuous improvement and people respect in its organization over the years which are the main pillars of Toyota’s way. Stewart & Raman (2007) elaborate in the words of Mr Watanabe that Toyota’s way is a never ending learning process as managers may learn what is above the surface but beneath is far deeper. That is why Toyota needs a workforce which is smarter and able to use smart technologies. According to (Schmitt 2019)

Toyota not only wants their plants being developed based on kaizen philosophy but also their workforce to become faster, smoother and smarter. It is not possible to achieve objectives without obtaining the high performance management within a company because sometimes strategies fail due to the incompetence of the management. Sadun et al. (2017) also state that our research indicates that high performance management companies yield high productivity and growth and in the case of low productive companies their management fail to recognize their incompetence.

In the third step which is a successful implementation of an operational plan within a company which is not possible without a strategy based on core competencies and a high performance management culture. Smart technologies can be used like ERP and online dashboards to make the company's performance more visible and easier to monitor and evaluate the managerial performance. Smart technologies will also help to reduce time and make manufacturing processes more flexible. This flexibility will help the companies to make changes when needed for example when set targets are below the benchmark. Once a company successfully managed to digitize their whole operational and sales activities using data analytics and AI; they can forecast supply, demand, increase/decrease in raw material prices and many other aspects related to operational and sales activities. The smart technologies can help companies to steer in a right direction and to maintain adequate resources to meet the future demands and can re-shape the way the companies work. These smart technologies are comprised of *physical system* i.e., mechanical, electrical parts etc., *smart components* i.e., software, embedded operating system, digital interface etc. and *connectivity* i.e., networking equipment, which allows a company to develop a new manufacturing infrastructure. It will not only help to develop new production processes but will also assist in the development of innovative featured products. This new infrastructure will allow companies to produce products which will be able to monitor, control and optimize their performance on their own and be able to learn on their own. The most important key is to develop a database where real time data can be stored, monitored, analysed and evaluated continuously in order to make forecasts related to supply/demand and this data will also help to make improved product designs and production processes. (Porter & Heppelmann (2015) illustrate that it will transform every manufacturing company into a software company where R&D and IT combined together gives a concept of a data organization. A company where software engineers will be product and production process designers who will design new products and processes at low cost with evergreen designs that can be modified by using augmented reality and other similar tools; hence this transition is a crucial part of the process.

Augmented reality is a technology which transfers data and analytics into images and animations and overlay them on the physical world. Porter & Heppelmann (2017) argue that since humans get 80% to 90% of information from their vision and this technology provides not only a visual image but also analytics so it is the so far best tool and companies can benefit from it not only in manufacturing but also in other function of a company. In one example, Newport News Shipbuilding Company uses AR to design and manufacture ships. This tool helps them to minimize defects in design and in manufacturing process. It helps the company to save considerable time and cost. In one other example, Boeing uses AR to assemble aircrafts, as AR also transform analytics so Boeing employees can assemble aircraft parts together step by step as instructed by the AR. So, this technology not only visualize but also interact and guide them in not only manufacturing process but also in logistics, marketing and after sales.

Similarly, D'Aveni (2018) also advocates highly in the favour of 3D printing and insists that it is only way of going forward as many companies are implementing it. Although D'Aveni, (2018) seems to be not a fan of industry 4.0 (the concept originated in Germany) as he argues that it will create strategic complications and strategic inflexibilities. There is no doubt that 3D printing embedded with digital technologies will help to increase production, decrease cost and design innovative product designs as in one example, Nike is using 3D printing to manufacture complex shoe soles which is hard to manufacture conventionally. The important thing is that companies should not rely on one technology alone but they should use it along with other smart technologies. On the downside if every company buys AR and 3D printing technologies than what will these companies do and how they will achieve competitiveness? That is why every company requires a strategy based on resources, capabilities and workforce as discussed in the first and second step. It also requires a database to work with these technologies and it is the only way to achieve a sustainable competitiveness. The idea of implementing smart technologies will help to convert a manufacturing factory into a smart factory comprising of simplified components, reconfigurable assembly processes and continuous production operation by using smart technologies collectively. It will also help in logistics, marketing, after sales, security and upgraded human resource to work with smart technologies.

In the fourth step managers are required to monitor continuously all the operational activities and make adjustments where needed. Action oriented reviews should be done to resolve issues immediately when they arise based on the given data and information in hand. This practice will help managers to spot weak points in the management system and provide them with enough flexibility to resolve them timely. Last step is overall strategy overview where managers are required to analyse statistical data, cost and profitability reports and evaluate fulltime performance of a company. This final part is especially important as this process will close the loop of the management system. It is also important if managers desire to make modifications in strategy and operational plans based on the data and reports because it will improve the overall management system and helps the managers to adapt it fully in order to accomplish the long term objective of sustainable competitiveness.

### 2.3.7 Flexible Products

In recent years' product designing have gained popularity in the manufacturing sector and now it is termed as a crucial part of product development. According to Boonman et al. (2015) flexibility is a competitive tool that can be used in markets filled with large number of flexible product manufacturers. According to Page et al. (2002, p.133) a study shows that 75% of respondents said that product design is the major reason of consumer attraction towards a particular product. Page et al. (2002) contend that there has been lots of literature available on the product design and its aesthetics but there is some literature available related to functionality of the product. Product functionality is an essential part of product design as in one example of VW beetle; it became popular in the consumer market because of its unique design and it stayed successful for a long time because of its functionality. Although there has been a lot of criticism on product design and functionality of the car but it remained popular car for decades.

Spence et al. (2011) state that consumers approach towards a certain product is based on their cognitive judgments and consumers make buying decisions about a particular product after having positive vibes from the product. This cognitive judgment may vary across consumers and products. Normally in consumer products; consumers fall for the aesthetic perspective of the product. On the other hand, some consumers fall for product quality which is not defined by the aesthetics of the product. For that purpose, usually consumers look for functionality perspective of the product. According to Page et al. (2002) functional characteristics of the product help consumers to evaluate and judge products on the basis of quality. Brand names also have a significant impact on the quality judgment by the consumers. A brand name like BMW brings a sense of quality and high functionality of a product so consumers may judge the product on a different criterion but on the other hand in the case of a low value brands; a consumer's cognitive judgement may differ in evaluating the products functionality. Vinokurova (2019) also argues that operations department can add or remove functional dimensions of flexibility in any given product and then marketing team creates demand for that particular product. In this way they make consumers adapt to the new product psychologically. They move consumers from one level of product utility to another.

### 2.3.8 Flexible Product Development Strategy – Product Process Matrix

Every company develops a strategy regarding new product development. It involves product features mainly like flexibility and standardisation in the products. Some companies opt for a standard product as it is aimed for producing one product for each and every consumer while on the other hand; some companies opt for flexibility feature as a prominent feature in their products to attract their consumers. Lafou et al. (2016, p. 99) has defined flexibility as "the sensitivity of a system to change as more flexible the system; less sensitive to changes occurred in the environment". Once a company decides to adopt flexible product strategy; they will embark on new product development process. According to Oliveira (2017, p. 1326) there are three major forms of flexibility; operational flexibility, product flexibility and capacity flexibility. Flexibility in product is defined by Schneider et al. (2020, p.814) as "the ability to adapt to change easily and reversibly whereas economically understandable easily and changeable back to the previous position rapidly". Product flexibility is also defined by Suh et al., (2007, p.68) as the capability of a system to undertake specified changes of classes with ease. The basic reason why companies go for products with flexibility feature is to capture all segments of consumers because with one standardised product a company cannot market all consumer segments. According to Fu et al. (2017) flexible products allow manufacturers to avoid potential mismatch for consumers.

Alptekinoğlu et al., (2019) aver that now consumers demand a single product with multiple variations; in short, they expect a product to be flexible in terms of functionality so that larger consumer segment can take benefit from the product. For example, insulin pens with an option of adjustable insulin dosage. It can help consumers to adjust insulin according to their needs and also helps the company to capture larger market share and profits on the basis of flexibility attribute. In one other example in the case of medical devices like pacemakers and hearing aids, now companies have developed products like now a pacemaker can readjust itself according to the heart condition of the patient and similarly hearing aids now can adjust themselves according to their surroundings.

The motivation behind the idea of flexible product development is to answer variation and changing consumer demands over time. It also requires a technology to manufacture these kinds of products. A technology that can offer modularization in the product is an essential need to produce products with flexible features. Krajewski et al. (2013, p.115) have given a product process matrix that explains how different manufacturing processes can be adopted to manufacture products. However, manufacturing process structure does not provide a lot of flexibility but it does provide mass customisation with low volumes which allows producing flexible products other than standard products on the assembly lines or sub-assembly lines of the manufacturing system. Fritzsche et al. (2020) also argue that a certain level of flexibility is needed in the existing production line to develop a different variant of the product otherwise a new production line would be required to develop different variants of the existing product. Given the fact that consumers have been changing demands continuously and there is a variation in their preferences; companies usually opt for two kinds of strategies, *1. Standard product:* in this strategy a company decides to offer multiple standardised products to capture major number of consumer segments. *2. Flexible product:* in this strategy a company decides to offer a reconfigurable product which has variation in functionality so that major number of consumers can utilize the products to fulfil their needs.

Alptekinoğlu et al., (2019) state that they found that flexible products dominate standard products if they offer greater customer value through their developed theoretical model. They have also found an interesting relationship between product strategy and customer preferences in their study. Alptekinoğlu et al., (2019) avow that there are three possible consequences for companies when they produce flexible products. First, they have to reconsider the pricing of their product because from variety of standardised products now they are selling one flexible product. Secondly, now companies may have given variety in their flexible product by offering them post purchase utility choices. Thirdly, companies may have empowered the consumers to do the reconfigure task of the product according to their changing needs. At this point the need of new product development arises which is flexible and reconfigurable to perform multiple tasks. This third approach leads to mass customisation. The three consequences described by Alptekinoğlu et al. (2019) are being explored in detail. It will help to understand why flexible products are becoming essential more than ever to fulfil consumer needs.

### 2.3.9 Flexible Products and Utility Choices

According to Alptekinoğlu et al. (2019) standard products can cause misfit cost to the consumers which can result into failure in the product strategy. On the other hand, in case of flexible products, there is a reconfiguration cost; if that cost is higher than a consumer might not be inclined towards the product no matter how much the product is flexible. There is another interesting fact to note that flexible products are more likely to satisfy the changing consumer needs over time because flexible products are ideal products when there is uncertainty in terms of consumer preferences. Herpen et al. (2019) argue that organizations should produce products that offer utility that doesn’t go beyond consumer needs. It will help to avoid product disutility. However, when consumer’s preferences are not static and they tend to change over time; that means consumer’s preferences are volatile which can lead to uncertainty. Nonetheless, standard products can also be profitable in the case of extremely low or high uncertainty in consumer preferences. It is also observed that flexible products are more suited for forward-looking consumers; the kind of consumers who favours innovation and novelty. Moreover, sometimes companies follow a hybrid product strategy where they offer both flexible and standard products in order to counter heterogeneity in consumer preferences. For example, Google App Engine, a cloud computing platform offers two different environments; one is standard and second is flexible. According to Alptekinoğlu et al. (2019) so far there are not a lot of studies that have been advocated the issues related to evolving consumer preferences and flexible products. Alptekinoğlu et al. (2019) suggest that in the new product development; technology plays a significant role. Especially the technologies that can help companies to enhance the ability to reconfigure and to redesign the flexibility of the products which is the chief concern here. For example, an improved programmable hearing aid that can be used electronically. It can be only possible with state-of-the-art defect free manufacturing technologies.

### 2.3.10 Flexible Products and Mass Customisation

When companies are following mass customisation normally, they use customised product strategy while on the other hand flexible products offer choice and variety beyond point of purchase and delays product differentiation. Alford et al. (2000) define mass customisation as “mass customizers develop, purchase, market and distribute goods and services with such verity that nearly everyone finds what exactly they want at the price which they can afford to pay.” (Alford et al. 2000, p.100) The concept of mass customisation supports consumer driven industrial system by developing business agility. Business agility can be developed through combining customisation and mass production. Rousseau et al. (2021, p.103) state that according to a survey market trends show that approx. 30% consumers have shown willingness to purchase customised products. This research proves that three out of ten consumers are ready to customise their own product according to their needs and more consumers will follow this trend in near future. The most important finding of this study is that all the respondents are willing to pay for their customised products.

This trend provides an opportunity but this opportunity comes with the challenges. First, developing a configuration mechanism appropriate for consumers is a time-consuming task which can result into complications on the manufacturer’s end. Secondly, consumer preferences have very short lifecycle; they can change over time. So, configuration system also needs to change when consumer preferences change. Sakao et al. (2017) say that modularity in the manufacturing system is a key towards mass customisation. Modularity can help to minimize complications and ease the manufacturing process which would make mass customisation easy and faster for the consumers. Srinivasan et al. (2018) state that 3-D printing can offer mass customisation rapidly to cater the short cycle time. Moreover, 3-D printing can also solve the problem of manufacturing process flexibility as it has capability to produce mass customised products of any kind without consuming a lot of time on changing tooling equipment. Consequently 3-D printing reduces the need of wide range of tools and equipment and also reduces the cost of manufacturing. With the help of 3-D printing manufacturers can increase or decrease the production of customised products according to the need. Mass production might not be possible with 3-D printing but manufacturing costs can be reduced. One of the most important prerequisite for mass customisation is consumer data. Manufacturers are relied on consumer data to analyse consumer preferences and changing trends over time. Technologies like Big Data can help organisations to develop a product customisation system backed by data that can help consumers to customise products according to their preferences. Rousseau et al. (2021) claim that an online product configurator is the solution to the mass customisation problem. Product configuration system is a knowledge-based system that helps consumers to customise products according to their preferences with the available options.

### 2.3.11 Flexible Product Development System

An organisation requires flexible manufacturing system to produce flexible products at any given times. According to Palominos et al. (2019) a flexible product manufacturing system allows organisation to shorter product cycles and improved competitiveness. Flexible product development is important because it helps to deal with uncertainties however the decision-making process to develop flexible manufacturing is rather inadequate. It requires proper understanding and knowledge so that it would be economically productive and competitive. Zhang et al. (2009) argue that now firms are focusing on developing flexible manufacturing abilities so that they answer the changing consumer preferences over time. The development of flexible manufacturing strategy is a challenging task due to many uncertainties. According to Wang et al. (2019) these uncertainties might be uncertain processing time, uncertain processing cost and uncertain machine breakdowns which can result into the failure of whole production scheduling process.

Product development flexibility is an attribute which allows manufactures to produce multiple products in order to minimize potential losses due to change in consumer preferences or due to technology disruption. It will not only help manufacturers to act quickly to respond change in consumer preferences but also helps them to innovate new product designs in the process. Moreover, this attribute will also help manufacturers to elevate their capabilities of producing new products and to improve their manufacturing processes as a whole. As it also contended by the Asadi et al. (2019) that variety of products will only add into complexities of the manufacturing process of a company. So, there is a growing demand in the consumer market of flexible products and it will drive companies towards flexible product manufacturing systems. Flexible product manufacturing systems are manufacturing systems that are based on mixed-product assembly lines. Their assembly lines are flexible and they can be used to produce products with variations according to the fluctuations in the demand of product mix.

Zhang et al. (2009, p.144) raised two aspects related to new product development and its functional flexibility. These two aspects are product concept flexibility (CF) and product prototype flexibility (PF). CF is an early stage of product development and at this level firms explore and conceptualize several ideas for new products. The next phase of product development is producing product prototype. A product prototype is used for consumer feedback, engineering checks and product testing in order to ensure that when this product goes for mass manufacturing it is error free and grabs consumer attention. It is very important that both CF and PF work together to develop a product that can attain consumer preferences. As it is discussed earlier that flexibility in the product development is the only way to produce products with absolute certainty that these products will meet consumer satisfaction. CF and PF are very important dimensions in order to produce variety of product concepts and prototypes as working models to achieve the ultimate goal of producing a product which meets consumer satisfaction.

First dimension CF is an ability of a firm to generate product concepts that can satisfy consumer needs. In the process a firm can develop multiple product concepts and send them for product development so that a new product can be developed in minimum possible time. In the traditional way of product development companies develop products and then modifies them according to the consumer feedback and market analysis. It is a time consuming and costly process while on the other hand CF allows companies to work out their concepts through R&D so that the goal of an error free product concept could be achieved. In the case of second dimension which is PF; it is an ability of a firm to produce physical models in less time as possible and most importantly with low cost. A prototype is like an artefact with having same attributes of products like functionality, quality and aesthetics. At this stage, a product designer can improve the functionality of the product to meet consumer satisfaction level. According to Zhang et al., (2009) prototypes are an excellent way of learning about unheard needs of consumers. It will help firms to adapt according to the rapid change in the consumer requirements. Many Japanese firms are using this strategy to responding change in consumer preferences in no time. At this stage several numbers of prototypes can be created and tested to develop a wider range of products.

Flexibility is an option which can have real positive impact on a new product development project. It is believed that literature does not fully reveal the significance of flexibility for a firm in the development of new product in a competitive market where the new product is going to be launched. Kettunen et al. (2015, p.893) suggests three segments in the new product development process. These three segments are *initial development, additional development and market phase*. At the first stage of initial development; a firm develops a product for the purpose of launching it into the market. During the developmental process, performance, desirability and functionality of the product are assessed on a certain criterion. At this stage a firm can make decisions like to continue or abandon the product development, what will be the cost of the product, which features to be added or not and which technology to be used for the product development. After the completion of initial development stage, the firm begins with second stage which is additional development. At this stage a firm may go to the third stage without adding additional aspects to the products. It is more of a review stage where progress of first stage is analysed and firms make sure that if something is required to be removed or added or not. Normally there is no time limit at this stage but firms try to further as quickly as possible to the third stage. After the completion of second stage firms launch their products into the markets. The third and final stage is market phase where newly developed product is launched to be tested for market performance.

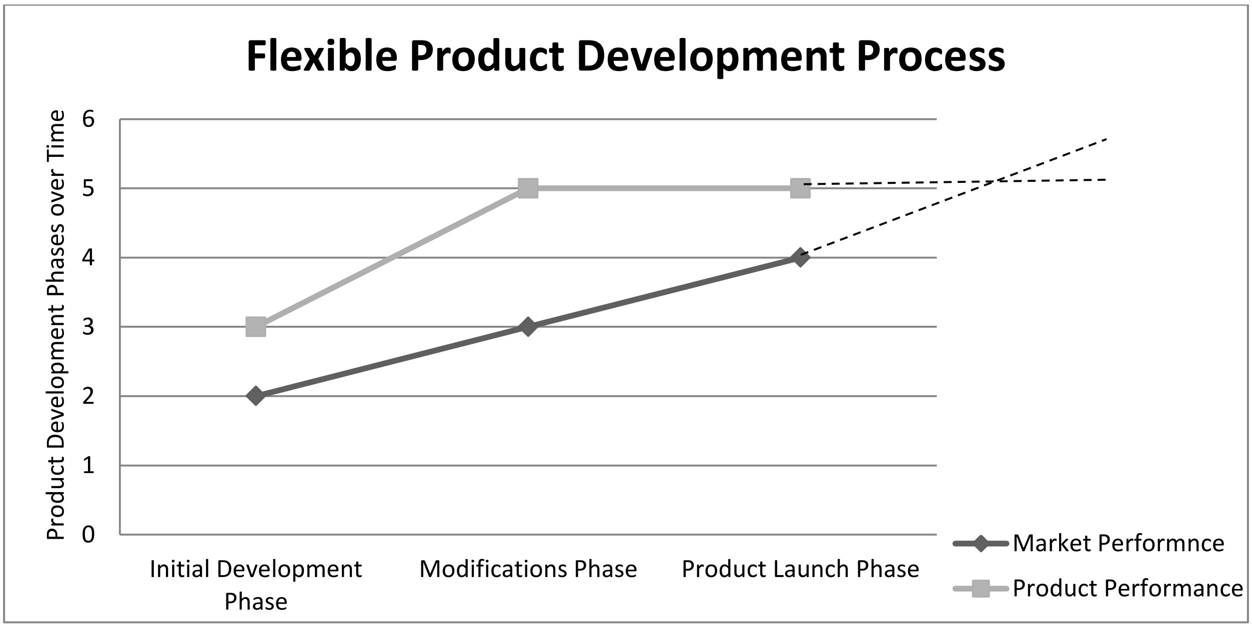


Figure 6: Flexible Product Development Process Source: (Kettunen et al. 2015, p.894)

In the fig. 6 it can be seen that new product development is a two-dimensional process. At first phase; a firm starts new product development with available resources and in the meanwhile market performance also grows in the time. At the second phase of the product development process, a firm decides to make amendments to the newly developed product if necessary. As the third phase approaches a firm launches its newly developed state of the art product which is superior to any other product available in the market. As graph shows that it remains superior for a time but as time passes; market evolves and competitors will launch products of their own surpassing your product. For example, Zara’s success is credited to the ability of rapid modifications in their product offerings. According to Arnett et al. (2018) it is instrumental for companies to redesign their products and services as in response to the changing dynamics of the marketplace.

It can be observed that this new product development process is based on the idea of CF and PF dimensions of new product development which was floated by Zhang et al., (2009). CF can be denoted as initial development process and PF can be regarded as additional development process. According to Jiang et al. (2019) firms should adopt consumer centric approach towards new product development. Consumer surveys are the best source of getting preferences pre-hand. This information can help companies as they can incorporate this data in the development of new product. It is believed that there is a strong relation between consumer preferences and new product development. However, consumer preferences may change over time and there are certain limitations if we try to develop a model based on consumer preferences because it is hard to predict future consumer preferences and accuracy of the collected data would be also in question.

# 3 Research Design & Methodology

The manufacturing industry faces growth and expansion challenges all the time. These challenges obviously require managerial attention and focus so that they can be addressed by improving the manufacturing processes. The activities in the manufacturing industry are rather complex and they require scientific solutions to the growing challenges of the time. According to Kumar (2014) research is not only a set of skills but it is also a way of thinking.

The impact of industry 4.0 technologies on the manufacturing industries is a truly relevant topic at this time. The impact contributes to the performance improvement on various grounds in the manufacturing sector. This scientific research aims to deliver a scientific study on the implementation of Industry 4.0 technologies and its impact on the performance. In this regards, individual researchers are always free to choose the methods, techniques and procedures that best meet their need and purposes.

According to Zikmund et al. (2009) a research design includes a detailed, systematic outline of the research methodology. The process of data collection and analysis is defined in the quantitative exploratory research. For economical and time reasons, an online questionnaire has been designed supported by Microsoft forms platform. The questionnaire has been prepared in a professional manner and host website collects the data. The data can be downloaded in the form of MS Excel. The core of this research is primary data which was collected from manufacturing companies of all sizes located in United Kingdom. The instrument that is used for data analysis is SPSS.

Zikmund et al., (2009) argue that the design phase is like a master plan of a scientific research based on methods and procedures for the purpose of collection and analysis of data. The structured research approach is based on data collection and analysis. Followed by general methodology, questionnaire design, pre-testing, final data collection and return ratios are discussed in the later stages.

The main purpose of scientific research is to evaluate the hypothesis against the gathered data. The impact of Industry 4.0 enabling technologies on the manufacturing sector will be tested and the hypothesis will be proved or disapproved accordingly. In the online survey approach, there are some advantages and there are some possible risks that are associated with this approach. For that purpose, a pre-test has been conducted to mitigate the possible risks in the data collection process. For the purpose of the research, the UK's manufacturing sector has been chosen to analyse how Industry 4.0 is affecting the UK's market and how UK's market is reacting to towards the industry 4.0 technologies.

### 3.1 Introduction to the UK Manufacturing Sector

The UK manufacturing sector is currently in the transition phase as UK has passed the factor driven stage of competitiveness where it depends on labour and natural resources (Alsmadi et al., 2012). In the developed economies like UK, services sector is always been a major contributing factor to the GDP. According to report on key economic indicators published by House of Commons Library, the UK manufacturing sector is accounted for 9.4% of total UK economic output while services sector is accounted for 81% of total UK economic output (Brien, 2024a and Brien, 2024b). The slowdown in the productivity growth in matured economies after the 2008-09 recessions was seen temporarily at the time, however, in the case of UK, this slow down seems to be affecting the productivity growth for a longer period of time. In the post-recession years, the labour productivity growth has been slowed to 0.1% from 1.9% in the UK. On the other hand, in the case of industries which are intensive users of digital technologies; their productivity growth has been reduced by 54% in the UK (Ark, 2016).

The UK government has initiated "Made Smarter Programme" to drive innovation and industrial digitalisation as The UK eyes to become the world leader of fourth industrial revolution by the year 2030 (Castaneda-Navarrete et al., 2020). This initiative targets to boost UK manufacturing up to £455B, productivity by up to 30% and jobs up to 175000 through industrial digitalisation in 10 years' time. There are two projects working under this initiative and these are *North West Made Smarter Adoption Pilot* focussing on Industry 4.0 technologies and *Manufacturing Made Smarter Challenge Programme* focussing on innovation.

'North West Made Smarter Adoption Pilot' was launched in 2018 helping 3000 SMEs to boost their productivity though Industry 4.0 technologies in north-west of England. The pilot programme has engaged with so far 1300 SMEs in the region; over 500 of them have received intensive support, over 180 have undertaken match funded transformation projects and 62 of them have undertaken 'Made Smarter Leadership & Training' across 3 universities in the north-west region (López-Gómez, 2021). The aim of this project is to create 'Regional

Growth Hubs' across north-west part of England. Project has been working for last 30 months and it seems to be a promising way to motivate manufacturers to adopt industry 4.0 technologies to increase competitiveness, exports and productivity (Castaneda-Navarrete et al., 2020). The early results compiled from 84% of the firms have shown 6.5% increase in turnover and 3.9% increase in the employment (López-Gómez, 2021).

The second project 'Manufacturing Made Smarter Challenge Programme' focuses on investment in the industrial digitalisation R&D and Industry 4.0 technologies. In 2019, a grant of £30M was given to identify the credibility and early success of the challenge at stage 1. The focus was on variety of the studies, ranging from feasibility to innovation demonstration. In the second stage, the project partners with the SMEs. The aim is to identify and removal of the barriers in the way of industrial digitalisation.

There are some key differences between the UK's Made Smarter Programme and international Industry 4.0 Initiatives. In other countries like Germany, China and Korea; Industry 4.0 initiatives are focussed on diffusion of technologies and best practice. The rationale behind it is that the Industry 4.0 technologies have not yet adopted by majority of the firms and already available digital technologies are cheaper, so governments supports the technology diffusion rationale nationwide. In other countries, Industry 4.0 initiatives have a national mandate and funded accordingly. However, UK lacks the technology diffusion programme for national coverage. In the UK, a regional pilot project is established and only north-west region is eligible for support.

In other countries, regional institutions have been used to deliver diffusion of technologies. Like in the US, "Manufacturing Extension Partnership" (MEP) supports technology diffusion in the firms across the US with their 600 offices and centres. Similarly, in Germany, "Federation of Industrial Research Associations" (AiF) has a network of 100 industrial research associations across the country been able to engage 50,000 firms in the country. In Japan, a network of 60 regional "Kohsetsushi centres" supporting industrial development and research to the firms. In the UK, Catapults are helping in the transition from research to the commercial delivery through R&D infrastructure, specialised knowledge and expertise. "High Value Manufacturing Catapult" (HVMC) is the largest in the Catapult network covering 17 locations across the country. Catapults do not have nationwide coverage across all regions and they do not support technology diffusion either as their peers across the seas.

HVMC model is inspired from Germany's Fraunhofer institutes and HVMC is not easily accessible due to high cost of support and membership.

In the UK, substantial efforts have been made to develop regional capabilities to deliver north-west pilot however, it is not just established yet like other countries. It is also not clear that regional institutions can support the national rollout of 'Made Smarter Programme'. Institutions like Catapult can play a vital role in this context by establishing a regional network and supporting firms across the country to support them in the industrial technology diffusion.

The data has been collected mainly from the manufacturing business established in the Yorkshire region. In the UK regional competitiveness; Yorkshire is among localities with an average score from 2018 to 2021. Yorkshire is among the worst performing locality in terms of competitiveness between the years 2018 and 2021 (Huggins et al., 2021). So it is safe to assume that businesses in this region are not performing well in terms of competitiveness and 'Made Smarter Programme' pilot project is initiated in north-west region, it does not include Yorkshire.

### 3.2 Online Survey Conduction and Questionnaire Design

A written survey by means of an online questionnaire has been used for the purpose of research. The use of online questionnaires is a pragmatic approach when it is being compared to the interview. The advantages of an online questionnaire include lower cost and less consumption of time. These days' lots of Masters and PhD students are relying on internet to conduct their thesis due to the technological advancements. One major advantage that outweighs any other disadvantage is the low cost of setting up an online questionnaire. Once the online questionnaire is live, researcher can only count the number of participants until it reaches the required number of participants. One another advantage is anonymity. Participants and research do not need to know each other and participants do not have to feel pressure to participate, it increases the honesty. One of the major inevitable limitations to the online questionnaire is self-selection bias. It means that respondents who are actually interested in the topic will fallout the questionnaire. This bias does not invalidate the results but requires careful interpretation of results (Dewaele, 2018). The questions are simple and specific in nature to avoid cognitive overload, so Likert scale questionnaires are preferred in the questionnaire to obtain maximum number of responses possible. On the downside, simple nature of questions may cause shallowness but it also can be avoided through mixed method approach by adding qualitative and quantitative data.

The method of choosing online questionnaire has been chosen for the following reasons.

- Evaluation of the results is anonymous as possible to ensure that all respondents have answered the questionnaire with honesty and openness as possible.
- An automated data collection tool is required to handle large numbers of respondents.
- The online questionnaire platform is easy to use; respondents can spend 5-10 minutes to fill out the questionnaire without any complicated steps.
- A hyperlink is being used to request the respondents to complete the questionnaire. It helps to avoid taking unnecessary storage space within the mailing system of the respondents.
- The online questionnaire has been made easy and convenient to use for the respondents in hope of attaining maximum number of participants possible.

It is also important to highlight any disadvantages of using online questionnaires for the purpose of research. Some of the disadvantages are listed below.

- It is a time consuming and difficult process to program an online questionnaire. A specialized online platform “Microsoft forms” has been used to design the online questionnaire.
- There are no high or specific IT skills required to formulate an online questionnaire on this platform. The hyperlink allows access to the participants to participate in the questionnaire in a digitally secure and protected way.
- Multiple participation in the online questionnaire can be avoided through built-in installed cookies.
- The identification problem can occur when it is not possible to make sure that the invited respondent is participating in the online questionnaire.
- The return-rate problem can arise when the respondent partially fills the questionnaire.
- Communication problems can arise from asynchrony in between the moment when questions arise and answered in the questionnaire. It is also mentioned that the clarification can only be asked upon the initiative of the survey respondent.

To mitigate the risks associated with the online questionnaire, the following measures has been taken apart from pre-testing.

- Participants were contacted through telephone/WhatsApp.
- Invitation emails were sent to the participants of the online questionnaire personally.
- Reminder emails were sent approx. after 2 weeks of the initial contact with the participants of the questionnaire.
- A valid email address was shared to all the participants via online questionnaire in case of any questions so that authenticity and validity of the survey can be maintained.

The online questionnaire only contained closed and selection type questions. It helped to increase the analysis process of the data collected. In selection type closed ended questions; respondents have a choice to select most suitable answer from the pre-defined options. A multi-level Likert scale is being used in this research. In this method, possible answers can range from agree to disagree and from being neither agree/disagree or neutral. According to Wenderoth, (2013) Likert scale type questions are commonly asked and they are quite easy to analyse in regard with averages, mean values and standard deviations. Moreover, single option questions are also used with pre-defined answers where respondents could select best suitable answer from them.

The questionnaire has been formulated into the following sections. The questionnaire is available in the appendix.

A. Introduction

An introduction of the researcher and the research has been given in the beginning of the online questionnaire. In the introductory part, confidentiality of the respondents has been assured and the general availability of the participation in the online questionnaire has been acknowledged.

B. Demographic Information

In this section, general questions have been asked from the respondents. The questions are related to the overall years of experience in the current field, the education level and the number of years of experience on a managerial position.

C. Organization Information

In this section basic information regarding the organization has been asked. The questions are related to the size of the organization and the use of Industry 4.0 technologies being used in the organization.

D. Readiness of Industry 4.0 Technologies Implementation

In this section, organization's readiness related to the implementation of Industry 4.0 technologies has been asked. The questions are asked related to the implementation process of Industry 4.0 technologies and Industry 4.0 as an organizational strategy. Furthermore, questions regarding how long the implementation has been started and a Likert scale to evaluate the readiness of an organization against several parameters have been asked.

E. Overall Equipment Effectiveness (OEE)

In this section, questions related to OEE in the manufacturing organization has been asked. The questions that are asked are related to current OEE level, impact of Industry 4.0 technologies on OEE and OEE after the implementation of Industry 4.0 technologies. Furthermore, a Likert scale has been included to evaluate different variables of OEE against the use of Industry 4.0 technologies in the manufacturing organization.

F. Competitiveness

In this section, a Likert scale has been given and respondents have been asked to select best possible option against various competitiveness factors which fit best to their organization in regard with Industry 4.0 technologies.

G. Circular Economic Strategies

In this section, questions related to circular economic strategies has been asked. It is known fact that the organizations which adopt Industry 4.0 implements some or fully circular economic strategies for economic or environmental reasons. The questions are asked related to what kind of and how many circular strategies has been used the organization and a Likert scale has been given to analyse the impact of using circular economic strategies on the organization in respect with Industry 4.0.

In the last, there is a question which is an open ended, has been asked if respondents like to share their opinion or comment regarding the research. After that there is a thank you note to acknowledge the valuable time that they have given to fill out this online questionnaire.

The questionnaire is subject to evaluation and pre-testing so that maximum output can be gained from it. It is important to verify the clarity in the content of the questionnaire. The questionnaire has been shared with the available experts and necessary adjustments have been made in the light of their comments so that it could be used in an uncomplicated way. Due to the diverse nature of the questionnaire, mostly Likert scale questions has been asked as they are easy to respond and convenient to attain feedback from the managers.

The survey was conducted online through Microsoft forms for the purpose of research and analysis focusing on production/operation managers and production/operation assistant managers. The survey was focused on the production managers and assistant managers so that actual data and information related to the role of Industry 4.0 in the manufacturing process can be gathered and analysed. The respondents have been identified and contacted through their valid addresses and asked to fill out an online questionnaire. It helped to save time. In this regard, cooperation is essential form the respondents to fill out the questionnaire. Respondents were given ample amount of time to fill out the online questionnaire and were asked again for a follow up to make sure if they have filled it out or not yet.

The phase of online survey through the help of a questionnaire lasted approx. 16 weeks of time. The data was collected from the production managers and assistant managers based in the UK. In some cases, it took longer to collect data as mangers had limited knowledge about the questionnaire. Then the situation and research objectives were explained to them so that they could be able to fill out the questionnaire with the most valid answers possible. The total communication is conducted in English and there any questions and concerns about the questionnaire has been explained and answered, so that they could be fill out the question with honest answers possible. The average time that respondents took to complete the online questionnaire is 5-10 minutes. In some cases, assistance was offered to the respondents to complete the questionnaire.

Given the nature of the research, manufacturing organizations of all sizes has been targeted in the research. The population includes small, medium, and large-scale manufacturing enterprises. The online questionnaire is aimed towards the production/operations manager or assistant manager overseeing the manufacturing processes in these enterprises. Wenderoth (2013) argues that the size of an organization can be determined through the number of the employees or turnover of the organization. It is not a valid criterion to evaluate the size of an organization as organizations with a small number of employees can have higher turnover than the organizations with large number of employees. There is a relationship between innovation activity and the firm size. The innovation activity is termed as innovation output and innovation activities per number of employees are termed as innovation rate. The innovation rate is a reliable way to measure innovation activity of a firm as it is also weighted with industry and firm size (Acs & Audretsch, 1988). The data shows that the large firms with at least 500 employees have shown more innovation activity then the smaller sized firms in the manufacturing sector. The firms are more innovative because they are capital intensive as they invest in R&D, technology to boost their innovation rate while small firms have to rely on universities for their R&D projects due to lack of financial resources. Hence, this dissertation has been using the size of an organization based on number of employees to measure their Industry 4.0 readiness, implementation of Industry 4.0 technologies and competitiveness.

## 3.3 Sampling and Data Interpretation Approach

An American based company Dun & Bradstreet has gathered information on manufacturing companies from trusted sources working in the United Kingdom. The business directory is comprised of 214397 manufacturing companies. A simple random sampling technique is being used and sample size is set to be 600. The sample size is chosen from the Yorkshire region of England. Some of the major industries have been identified from the business directory and random strata sampling method is adopted based on the organization size. There are three strata and sample size is divided among them. A random group of businesses have been selected to each stratum across various manufacturing sectors by using simple random sampling to avoid any bias. The business directory provides the company information along with the email addresses of the key decision makers working in different capacities. The message with the cover letter is being sent to them along with the gentle reminders and requests for their participation. A limited number of respondents share their office email and contact numbers as well.

Sharma (2017) asserts that this approach provides an equal opportunity to each member of the population to be selected as the respondent of the research. This approach is considered as a good approach and it involves more work, however, it is much more precise than other techniques as well. The sample size was estimated to be approximately 150 to 200 respondents from manufacturing organizations based on the nature of the research. Canco (2017) claims that more than 150 respondents should be sufficient for the purpose of the research. Moreover, Hsu et al., (2009) claim that minimum sample size of 146 is suitable based on their model and its application on a manufacturing facility located in Taiwan. The questionnaire was sent online to managers working in the manufacturing role within the selected population.

The total number of participants who responded was in total 165 and the response rate is 27.5%. Wenderoth, (2013) claim that the response rate above 15% is classified as good. According to Wu et al., (2022) the average response rate of an online survey is 34%. This study has below average response rate since there are several factors that affect the response rate mainly nature of the topic and type of the respondents.

Table 3 presents the total sample size and the participation rate of the respondents in this thesis. On the other hand, the table 4 shows that the sample size 600 manufacturing firms is spread over 23 industries out of 86 with in the UK manufacturing sector.

*Table 3: Sample Size and Participation*

| **Category** | **Sample Size** | **Total Participation** | **Percentage** | **Adjusted Percentage** |
|---|---|---|---|---|
| Small Size Enterprises | 200 | 52 | 31.1% | 31.5% |
| Medium Size Enterprises | 200 | 46 | 27.5% | 27.9% |
| Large Size Enterprises | 200 | 67 | 40.1% | 40.6% |
| **Total** | **600** | **165** | **98.7 %** | **100 %** |
| Missing | | 02 | 1.3% | |
| Total | | 167 | 100% | |

*Table 4: Manufacturing Industry Sectors*

| Manufacturing Industry | Total Population | Total Participation |
|---|---|---|
| Animal Food Manufacturing | 29 | 8 |
| Beverage Manufacturing | 42 | 15 |
| Computer And Peripheral Equipment Manufacturing | 22 | 14 |
| Electrical Equipment Manufacturing | 14 | 6 |
| Basic Chemical Manufacturing | 12 | 5 |
| Hardware Manufacturing | 38 | 11 |
| Engine, Turbine, And Power Transmission Equipment Manufacturing | 33 | 9 |
| Industrial Machinery Manufacturing | 43 | 7 |
| Agriculture, Construction, And Mining Machinery Manufacturing | 5 | 1 |
| Bakeries And Tortilla Manufacturing | 31 | 8 |
| Dairy Product Manufacturing | 27 | 4 |
| Cement And Concrete Product Manufacturing | 25 | 12 |
| Cutlery And Hand tool Manufacturing | 16 | 3 |
| Footwear Manufacturing | 18 | 5 |
| Glass And Glass Product Manufacturing | 5 | 2 |
| Alumina And Aluminium Production And Processing | 20 | 4 |
| Apparel Accessories And Other Apparel Manufacturing | 26 | 7 |
| Architectural And Structural Metals Manufacturing | 35 | 4 |
| Electric Lighting Equipment Manufacturing | 19 | 6 |
| Medical Equipment And Supplies Manufacturing | 30 | 8 |
| Metalworking Machinery Manufacturing | 23 | 6 |
| Motor Vehicle Parts Manufacturing | 47 | 16 |
| Plastics Product Manufacturing | 40 | 4 |
| **Total** | **600** | **165** |

One of the basic aims is to adopt evaluation approach to process and interpret the data that is most suitable for this research. A two-step approach has been adopted to process the data in this research. First step is univariate techniques which are being used to analyse the data in the descriptive way. In the second step, bivariate techniques have been used to test the hypothesis of this research.

The data analysis in the descriptive way has been conducted by using univariate techniques. It is important to gain valuable information by using single variables and indices. In this regard, percentages, diagrams, and tables have been developed. The technique selection has been made the way questions measured the data. Moreover, the factors like transparency and visualization of data were also considered.

Figures are used to illustrate standard deviation and arithmetic mean by using data gathered from questions like Likert scale. When the basic population is small, arithmetic mean is heavily affected so additionally, median is added. Nominal scaled variables have been illustrated to gain deeper insight into the data structure by using absolute and relative frequency. Additionally, graphical instruments have been used like pie charts, bar charts and point diagrams. Moreover, different indices, diagrams and tables have been used to demonstrate complex relationships.

In the second step of the research, bivariate techniques have been used to illustrate key research results. The usage of variables and the statistical techniques have been outlined as follows. According to Wenderoth (2013) the validity and operationalization of a hypothesis is defined how it is empirically tested. Consequently, indicators have been developed supported by the literature. These indicators refer to the target criteria and the collection of results from the single indices that is integrated with the indices.

The statistical method of correlational analysis was used for the purpose of the analysis of the hypothesis. Correlational analysis is a statistical technique that is used to examine the scale and significance of a relationship. It is used to measure correlations, casual connections, and the estimation of prognosis. It is also used to validate structures and logical coherence of the developed hypothesis. In simple terms, correlation analysis is being used to test the strength and direction of two independent variables. This study has used correlation analysis to evaluate the developed hypothesis.

The descriptive statistics is being used to verify the research while statistical analysis is being used to analyse the relationships between different variables and confirm the hypothesis. In this regard, data processing has following considerations.

- In the descriptive statistical analysis, the method is aimed to draw an analysis from real business world based on the opinions of professionals. This method is used to identify the problem, limitations and consequently define the solutions. The descriptive statistical analysis is used to verify the hypothesis and used to analyse the general characteristics of the data. However, given the complexity of this research with respect to Industry 4.0 and its impact on the manufacturing organizations, other statistical methods are also being used. Nonetheless, for nonparametric data, descriptive analysis is used. All these methods are used jointly and/or separately to materialize this research study.

- The statistical tools are being used for the purpose of data processing. The aim was to find the evidence to validate the hypothesis and achieve the research goals. Canco (2017) claimed that the role of statistics in the research is like a functional tool used for designing the research, analysing the data, and drawing the conclusion from it.
- The data which is being obtained from interviews is a non-parametric data. The univariate techniques will be used to analyse the data against the hypothesis.
- The data collected from online questionnaire is a parametric data and bivariate techniques have been used to analyse the data. Software Statistical Package for the Social Sciences (SPSS) has been used to analyse the data. All the hypothesis has been tested through this software package and their results are validated by the same software as well.

The interpretation of the data is one of the essential and crucial parts of the research. According to Canco (2017) interpretation is important for simple reasons which are usefulness and utility of research findings; they both lie in the interpretation of the data. Kothari (2004) argue that interpretation is an art that can be learned only from patience and experience. Deductive and inductive reasoning has been used to conduct in depth analysis of the data as much as possible. These methods helped to conclude concrete, stable and realistic findings in this study. It is not an easy task to interpret the data in a professional manner, the researcher requires enhanced research skills to conduct the research.

Based on the above discussion, research has been conducted, conclusion has been drawn and recommendations have been made. Accepting the challenges in the way of research, it is aimed to formulate simple, realistic, and understandable conclusions. This research would definitely not help the production managers but also the policy makers working in the top management of the manufacturing organizations.

# 4 Results & Analysis

There are numerous methods that are being used for the purpose of quantitative measure of data analysis. However, the Likert scale is one of the popular method among researchers (Boone & Boone, 2012). The original Likert scale used 5 responses which were “Strongly Agree”, “Agree”, “Neutral”, “Disagree” and “Strongly Disagree”. Now different variations have been developed over the years which include 7 point and 11 point Likert scale. The nature of response options are also varied according to the nature of the research as well. The data can be analysed in a composite way or individually however, this study has chosen to analyse the Likert scale responses individually according to the developed hypothesis. Likert Scale was developed to measure the attitudes that can validated scientifically in 1932. An attitude can be defined as behaviour or a reaction to a certain situation and circumstances. Joshi et al. (2015) state that the attitude can also be based on the certain ideas and beliefs which are based on a subject. The problem that arises that how to measure these attitudes based on certain feelings and beliefs over a subject can be resolved with the help of the Likert scale. This is a tool which helps to measure these attitudes with a scientific validation.

According to Joshi et al. (2015), there are two different schools of thoughts with a different opinion about how to analyse the Likert scale. One school of thought considers Likert scale data to be ordinal while the other school of thought believes that it is interval in nature. The question arises whether the points in the Likert scale is equivalent or equidistant. Both school of thoughts agree that “Strongly Agree” is not equal to “Agree” however, the conflict arises if they are at equal distance or not. It is imperative to answer this question if Likert scale data is ordinal or interval before starting the analysis process. The first school of thought claims that there is a ranking order in the options available so it must be treated as ordinal. On the other hand, the second school of thought claims that the aim of the Likert scale is to analyse the composite results so it has to be treated as interval data. It can be concluded based on the argument that if Likert scale is being analysed altogether then it is interval but if it is being analysed by each item then it is ordinal in nature.

Guerra et al. (2016) argue that there is a need to apply appropriate statistical tools to measure ordinal and interval data accordingly as there are practical implications attached to it. When interval data has to be analysed then a parametric approach has to be adopted while in the case of ordinal data, a non-parametric approach is more suitable option. It is important that ordinal data should not be treated as interval data but dataset and objectives of the research has to be taken into account before making such a decision. It can help to avoid misleading results and misinterpretation of results. Allen & Seaman (2007) insist that Likert scale has to treated as ordinal data initially and should not use parametric statistical tools. However, at the later stage, parametric tools maybe be used on individual items as a pilot study and also on the whole Likert scale.

### 4.1 Descriptive Result & Analysis of Respondents

The data collected in the survey shows in the fig. 7 that more than half of the respondents have the professional experience of over 15 years while less than 20% of respondents have the professional experience of 10-15 years. A little over 20% of the respondents have the professional experience of 5-10 years, however, less than 10% respondents have the professional experience of under 5 years. The results have shown that more than 90% of the respondents have professional experience of more than 5 years and they have enough experience working in the industry.

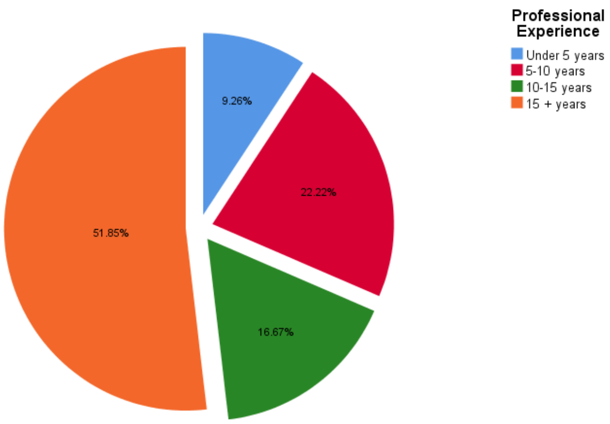


Figure 7: Professional Experience

It can be noted from the results depicted in the fig 8 that roughly 55% of the respondents have under 5 years of managerial experience while 15% of the respondents have 5-10 years of managerial experience. It can also be observed from the fig. 14 that less than 10% respondents have managerial experience of 10-15 years. However, just over 20% of the respondents have managerial experience of more than 15 years. The results have shown that more than half of the respondents have not much experience in the managerial capacity which also means that they have lot to learn in their respective roles. The lack of managerial experience may reflect to the results of the survey however, they have responded to the best of their abilities.

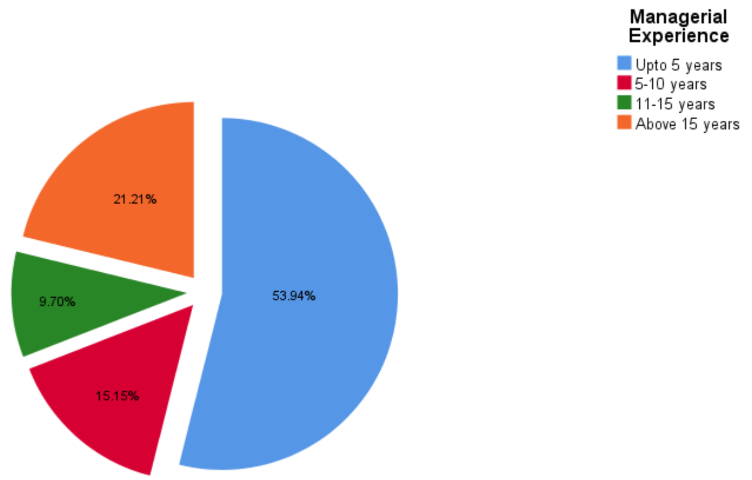


Figure 8: Managerial Experience

It can be observed from the fig.9 that the almost half of the respondents have attained education up to bachelor’s level however, 40% of the respondents have just graduated high school. Moreover, it can also be observed that a little over 10% of the respondents have attained the master’s degree. There were no PhDs in the respondents. It can be analysed from the survey that majority of the employees working in the manufacturing sector have high school and bachelors level education. Many of the respondents have joined their respective organizations as technicians or in a non-managerial roles and being promoted to the managerial positions after years of service.

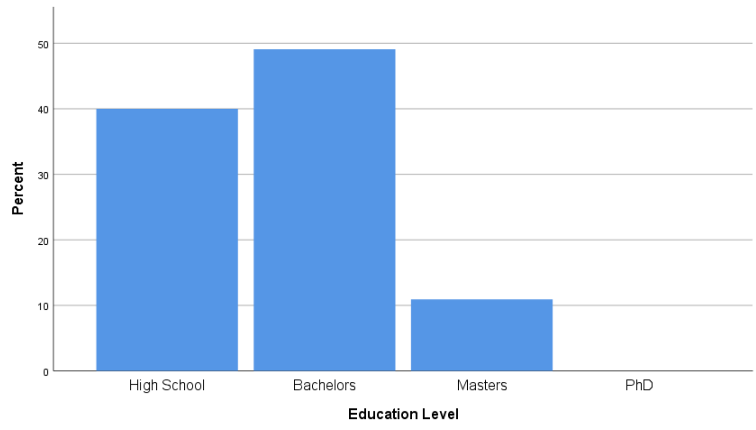


*Figure 9: Education Level*

The survey had also asked the respondents about their field of education in addition to their education attainment level. In the fig. 10, the results have revealed that over 60% of the respondents have graduated in the subjects related to social studies. Roughly 30% of the respondents have been graduated from engineering sciences while less than 10% of the respondents have been graduated from the natural sciences.

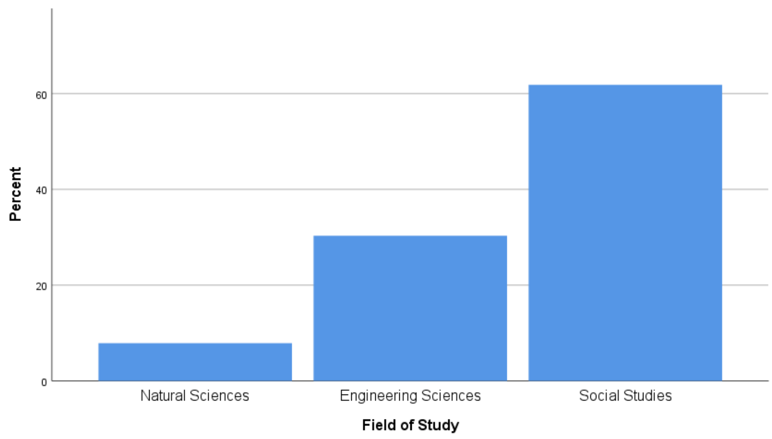


*Figure 10: Field of Study*

The fig. 11 represents the size of the organization where respondents are being employed. the organizations are classified based on their number of employees. The results have revealed that the data has been collected from a little over 30% small organizations while just under 30% organizations are from medium sized organizations. It can be also observed that 40% of the respondents are being employed in the large organizations. The results of the survey have shown a blended picture of the organization size with respect to the number of employees.

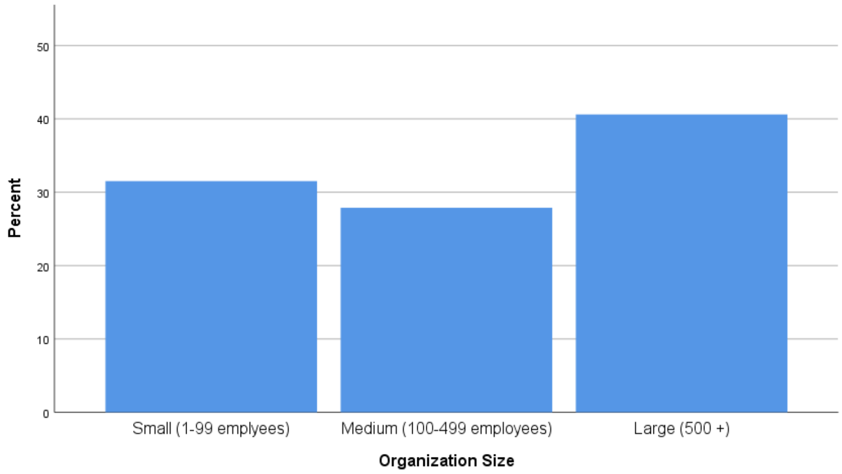


*Figure 11: Organizational Size*

## 4.2 Empirical Results & Analysis

In empirical research correlation determines the changes in the two outcomes. Pearson correlation is a popular tool that is being used by the researchers however, Spearman rho is another popular tool is widely used in the research community (Liu et al. 2016). Unlike Pearson, Spearman rho can be used to determine non-linear relationships. So, Spearman rho not only provides similar interpretation as Pearson but also works better on the non-linear relationships. According to Schober et al. (2018) Spearman is commonly denoted as "r" because of the ordinal data and it is unrestricted to continuous variables as it is robust against outliers. The spearman coefficient strength can be analysed as follows.

$$Strength = \begin{Bmatrix} Weak: 0.1 - 0.3 \\ Moderate: 0.3 - 0.5 \\ Strong: 0.5 - 1.00 \end{Bmatrix}$$

The Spearman coefficient ranges from -1 to +l while p=0 means no association between the two outcomes. The values close to +1 are considered to be strong positive and values close to -1 are considered to be strong negative correlation. Akoglu, (2018) argues that sometimes the interpenetration of these correlation coefficient differ based on the scientific research areas. There are no definite rules to determine the strength of relationships of two outcomes so authors are required to be mindful about their research works.

According to Sullivan & Artino (2013) the non-parametric tools do not make assumptions about the population from where the study data has been extracted. However, a large sample size is required in order to get effective results and outcomes. On the Likert scale, non-parametric tests like Spearman rho and others should be used instead of the parametric tests. Experts suggest that in the Likert scale, sometimes collected data is not normally distributed so it is best to use non-parametric tests. Parametric tests are useful only when data is normally distributed. On the other hand, Murray (2013) suggests that parametric tests can be applied on the Likert scale without any fear of getting wrong results. A study conducted by Murray (2013) reveals that parametric (Pearson) and non-parametric (Spearman rho) yielded similar results and a similar conclusion has been drawn from their results. The non-parametric tests are useful option for statistical tests for either nominal and ordinal data as these are not dependent on the distribution and neither on the mean, standard deviation or variance (Harris et al., 2008).

The author has made this additional effort to understand these tests in depth if they will affect the results or not. The study is using non-parametric test as it will yield no different results and it appears to be more suitable for the Likert scale. The lack of understanding about the Likert scale cause confusion especially Likert scale responses is the root of the confusion. Therefore, these responses have been tested independently and by using nonparametric tests. The different opinions can cause doubts in the research, so support from the literature is required to validate the statistical tests that are being used here.

### 4.2.1 Organizational Size

The study aims to measure the relationship between the organization size and the Industry 4.0 technologies. Industry 4.0 is a set of technologies and organizations may or may not implement all the smart technologies in their organizations. It is assumed that large organizations have a higher tendency for the adaptation of Industry 4.0 technologies while small organizations may show restraint due to various reasons. The second hypothesis is related to express if a positive relationship exists between the organizational size and implementation of Industry 4.0 technologies. This study has analysed this relationship with each & every technology that is included in the Industry 4.0 according to the available scientific literature.

H1: There is a positive influence of organizational size on the time since Industry 4.0 technologies been implemented.

The H1 suggests that the larger the size of an organization will be, the greater the chances that they have early adopters Industry 4.0 technologies. It is believed that large organizations have enough resources and less obstacles to adopt Industry 4.0 technologies.

*Table 5: Organization Size and Industry 4.0 Adoption Time*

| | | Organization Size | Industry 4.0 Adoption Time |
|---|---|---|---|
| Organization Size | Correlation Coefficient | 1.000 | .338** |
| | Sig. (2-tailed) | . | .000 |
| | N | 165 | 159 |
| Industry 4.0 Adoption Time | Correlation Coefficient | .338** | 1.000 |
| | Sig. (2-tailed) | .000 | . |
| | N | 159 | 160 |

**. Correlation is significant at the 0.01 level (2-tailed).

The results shown in the table 5 shows a positive significant relationship between the organization size and the adoption time of Industry 4.0 technologies. Although the strength of the relationship is weak, the importance of organization's size cannot be ignored completely. This relationship shows that the large organizations are tend to the early adopters of the Industry 4.0 and on the other hand, smaller sized organizations tend to be the late comers in the adoption of Industry 4.0 technologies. So, this study accepts the first hypothesis based on the results. The lack of readiness and un-fulfilment of the prerequisites are the potential causes of the weak relationship. Early adaptors of the Industry 4.0 implementation within their manufacturing not only gain lead in the competition but also gain a competitive advantage as an early adaptor. Organizations who adopt change at a slower pace or later lag behind in the competition especially in terms of technology.

H2: There is a positive influence of organizational size on the implementation of Industry 4.0 technologies.

According to Ejaz (2022) the technologies that are included in Industry 4.0 are robots, virtual/augmented reality, Internet of Things, 3D printing, Big Data, Cloud Computing, Simulations and ERP. The results that are being showed in the table 7 indicates that there is a positive relationship between organization size and ERP, Big Data and Cloud Computing independently but Internet of Things have shown a negative relationship with the organization size. It is also important to mention that the strength of the relationship is weak with the ERP while it is moderate with the Big Data and Cloud Computing. On the other hand, there is no relationship has to be found between organization size and 3D Printing, Simulation, virtual/augmented reality and robots.

The positive relationship that has to be found in only 4 technologies is also positive weak while Internet of Things have shown negative relationship with respect to the organization size. It can be concluded by the results that organization size is likely to be the reason for the implementation of the Industry 4.0 technologies. Organizations may adopt these technologies based on different reasoning. This study rejects the H2 and accept the alternative which is that organization size has nothing to do with the Implementation of Industry 4.0 technologies. It may play a small-scale role but not significant enough to accept the H2.

According to Sony (2020), the implementation of Industry 4.0 results in the horizontal and vertical integration of the organization. The change in the architectural design of the organization comes at a high cost. The breakeven point may come in the long term but initially the cost is so high that many organizations are forced to reconsider their decisions regarding implementation of Industry 4.0. Sony, (2020) says that the effectiveness of Industry 4.0 varies due to the size and location of the organizations. These academic findings are consistent with the results of the dissertation as there is no relationship between Industry 4.0 and organization Size. It is difficult for small and medium enterprises to implement Industry 4.0 due to insufficient financial capital. Moreover, the results shown in table 7 prove that there is a significant positive relationship between organization size and financial capacity. It can be deduced from the results that financial capacity is a major obstacle for organizations on their way to the implantation of Industry 4.0. This implementation brings a huge change in the

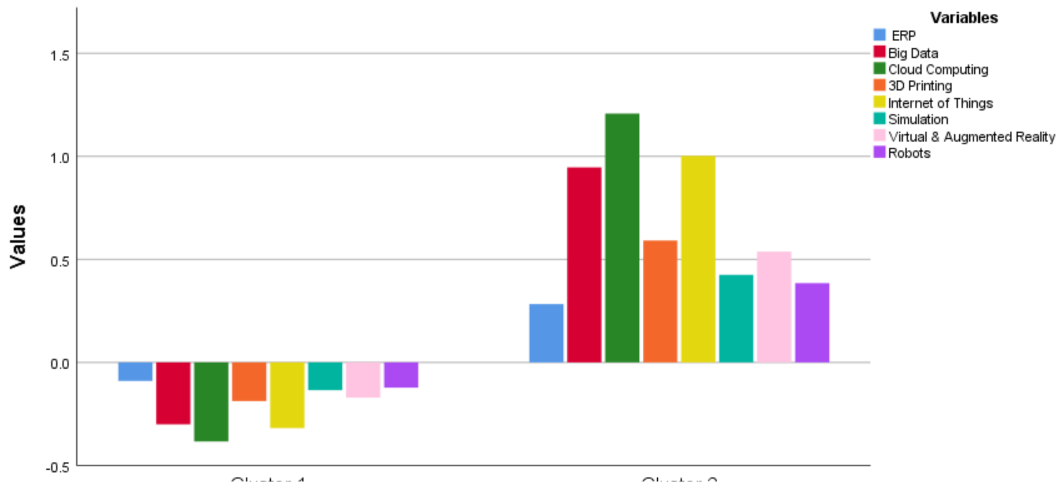




*Figure 12: Cluster Industry 4.0 Technologies Implementation*

*Table 6: ANOVA Results of Cluster Industry 4.0 Technologies Implementation*

| | Cluster | | Error | | | |
|---|---|---|---|---|---|---|
| | Mean Square | df | Mean Square | df | F | Sig. |
| ERP | 4.225 | 1 | .980 | 164 | 4.309 | .039 |
| Big Data | 47.204 | 1 | .718 | 164 | 65.719 | .000 |
| Cloud Computing | 76.836 | 1 | .538 | 164 | 142.927 | .000 |
| 3D Printing | 18.426 | 1 | .894 | 164 | 20.617 | .000 |
| Internet of Things | 52.921 | 1 | .683 | 164 | 77.436 | .000 |
| Simulation | 9.501 | 1 | .948 | 164 | 10.020 | .002 |
| Virtual & Augmented Reality | 15.256 | 1 | .913 | 164 | 16.708 | .000 |
| Robots | 7.816 | 1 | .958 | 164 | 8.155 | .005 |

The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

architectural design of the business and not every organization is ready to take this step.

The K-Means cluster analysis depicted in the fig. 12 tells that the values of Industry 4.0 technologies lie slightly below the mean in the cluster 1 while the values are higher than the mean in the cluster 2. The variables are being standardized to get accurate results for the clusters. In table 6, the ANOVA test tells that ERP, Simulation and Robots have no significant impact on the cluster and their F values are also low. The variables with elevated F values are cloud computing, internet of things and big data. They have the most significant impact on the cluster Industry 4.0 technologies implementation. Augmented/virtual reality and 3D printing also have a significant impact on the cluster however their significance level is low due to the low F values.

*Table 7: Spearman rho test for organization size & Industry 4.0 Technologies Implementation*

| | | | Organization Size | ERP | BigData | CloudComputing | 3D Printing | Internet of Things | Simulation | Virtual & Augmented Reality | Robots |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Spearman's rho | Organization Size | Correlation Coefficient | 1.000 | .294** | .446** | .345** | -.015 | .239** | .146 | .143 | .030 |
| | | Sig. (2-tailed) | . | .000 | .000 | .000 | .851 | .002 | .061 | .066 | .703 |
| | | N | 165 | 165 | 165 | 165 | 165 | 165 | 165 | 165 | 165 |
| | ERP | Correlation Coefficient | .294** | 1.000 | .267** | .157* | -.062 | .046 | -.089 | -.102 | -.008 |
| | | Sig. (2-tailed) | .000 | . | .001 | .043 | .424 | .560 | .255 | .190 | .922 |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | BigData | Correlation Coefficient | .446** | .267** | 1.000 | .423** | .022 | .249** | .097 | .142 | .030 |
| | | Sig. (2-tailed) | .000 | .001 | . | .000 | .777 | .001 | .213 | .069 | .702 |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | CloudComputing | Correlation Coefficient | .345** | .157* | .423** | 1.000 | .086 | .335** | .066 | .143 | .133 |
| | | Sig. (2-tailed) | .000 | .043 | .000 | . | .271 | .000 | .401 | .067 | .087 |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | 3D Printing | Correlation Coefficient | -.015 | -.062 | .022 | .086 | 1.000 | .221** | .306** | .187* | .006 |
| | | Sig. (2-tailed) | .851 | .424 | .777 | .271 | . | .004 | .000 | .016 | .941 |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Internet of Things | Correlation Coefficient | .239** | .046 | .249** | .335** | .221** | 1.000 | .078 | .147 | .090 |
| | | Sig. (2-tailed) | .002 | .560 | .001 | .000 | .004 | . | .316 | .059 | .246 |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Simulation | Correlation Coefficient | .146 | -.089 | .097 | .066 | .306** | .078 | 1.000 | .290** | .029 |
| | | Sig. (2-tailed) | .061 | .255 | .213 | .401 | .000 | .316 | . | .000 | .709 |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Virtual & Augmented Reality | Correlation Coefficient | .143 | -.102 | .142 | .143 | .187* | .147 | .290** | 1.000 | .219** |
| | | Sig. (2-tailed) | .066 | .190 | .069 | .067 | .016 | .059 | .000 | . | .005 |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Robots | Correlation Coefficient | .030 | -.008 | .030 | .133 | .006 | .090 | .029 | .219** | 1.000 |
| | | Sig. (2-tailed) | .703 | .922 | .702 | .087 | .941 | .246 | .709 | .005 | . |
| | | N | 165 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

*Table 8: Spearman rho test for organization size & Industry 4.0 Technologies Readiness*

| | | | Organization Size | Professionally Trained Workforce | Financial Capacity | Technical Capabilities | Installed Certified Hardware | High Speed Internet Networking | Firewall for Data Security | Awareness of Limitations | Knowledge of Manufacturing SOPs | Thorough Mapping of Operational Processes | Interactive Software for Production Ordering & Scheduling Capacity | Integration of Systems for Interoperability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spearman's rho | Organization Size | Correlation Coefficient | 1.000 | .135 | .340** | .327** | .295** | .139 | .255** | .269** | .166* | .145 | .274** | .249** |
| | | Sig. (2-tailed) | . | .084 | .000 | .000 | .000 | .082 | .001 | .001 | .039 | .075 | .001 | .002 |
| | | N | 165 | 164 | 160 | 160 | 157 | 158 | 156 | 156 | 155 | 151 | 158 | 158 |
| | Professionally Trained Workforce | Correlation Coefficient | .135 | 1.000 | .263** | .191* | -.002 | .143 | .250** | .150 | .101 | .257** | .296** | .282** |
| | | Sig. (2-tailed) | .084 | . | .001 | .016 | .978 | .074 | .002 | .060 | .209 | .001 | .000 | .000 |
| | | N | 164 | 165 | 160 | 160 | 158 | 158 | 157 | 157 | 156 | 152 | 159 | 159 |
| | Financial Capacity | Correlation Coefficient | .340** | .263** | 1.000 | .438** | .235** | .186* | .188* | .255** | .281** | .291** | .249** | .236** |
| | | Sig. (2-tailed) | .000 | .001 | . | .000 | .003 | .020 | .019 | .001 | .000 | .000 | .002 | .003 |
| | | N | 160 | 160 | 160 | 156 | 156 | 156 | 155 | 155 | 154 | 149 | 157 | 156 |
| | Technical Capabilities | Correlation Coefficient | .327** | .191* | .438** | 1.000 | .350** | .180* | .199* | .262** | .205* | .215** | .281** | .276** |
| | | Sig. (2-tailed) | .000 | .016 | .000 | . | .000 | .025 | .014 | .001 | .011 | .009 | .000 | .001 |
| | | N | 160 | 160 | 156 | 161 | 154 | 155 | 153 | 153 | 152 | 148 | 155 | 155 |
| | Installed Certified Hardware | Correlation Coefficient | .295** | -.002 | .235** | .350** | 1.000 | .350** | .225** | .294** | .261** | .223** | .209** | .343** |
| | | Sig. (2-tailed) | .000 | .978 | .003 | .000 | . | .000 | .005 | .000 | .001 | .006 | .009 | .000 |
| | | N | 157 | 158 | 156 | 154 | 158 | 155 | 154 | 155 | 153 | 148 | 156 | 155 |
| | High Speed Internet Networking | Correlation Coefficient | .139 | .143 | .186* | .180* | .350** | 1.000 | .342** | .032 | .206* | .187* | .394** | .277** |
| | | Sig. (2-tailed) | .082 | .074 | .020 | .025 | .000 | . | .000 | .693 | .011 | .023 | .000 | .000 |
| | | N | 158 | 158 | 156 | 155 | 155 | 159 | 154 | 154 | 153 | 149 | 156 | 155 |
| | Firewall for Data Security | Correlation Coefficient | .255** | .250** | .188* | .199* | .225** | .342** | 1.000 | .179* | .330** | .203* | .327** | .370** |
| | | Sig. (2-tailed) | .001 | .002 | .019 | .014 | .005 | .000 | . | .026 | .000 | .013 | .000 | .000 |
| | | N | 156 | 157 | 155 | 153 | 154 | 154 | 157 | 154 | 153 | 148 | 156 | 154 |
| | Awareness of Limitations | Correlation Coefficient | .269** | .150 | .255** | .262** | .294** | .032 | .179* | 1.000 | .372** | .185* | .241** | .356** |
| | | Sig. (2-tailed) | .001 | .060 | .001 | .001 | .000 | .693 | .026 | . | .000 | .024 | .002 | .000 |
| | | N | 156 | 157 | 155 | 153 | 155 | 154 | 154 | 157 | 153 | 148 | 156 | 154 |
| | Knowledge of Manufacturing SOPs | Correlation Coefficient | .166* | .101 | .281** | .205* | .261** | .206* | .330** | .372** | 1.000 | .148 | .279** | .375** |
| | | Sig. (2-tailed) | .039 | .209 | .000 | .011 | .001 | .011 | .000 | .000 | . | .074 | .000 | .000 |
| | | N | 155 | 156 | 154 | 152 | 153 | 153 | 153 | 153 | 156 | 147 | 155 | 153 |
| | Thorough Mapping of Operational Processes | Correlation Coefficient | .145 | .257** | .291** | .215** | .223** | .187* | .203* | .185* | .148 | 1.000 | .215** | .293** |
| | | Sig. (2-tailed) | .075 | .001 | .000 | .009 | .006 | .023 | .013 | .024 | .074 | . | .008 | .000 |
| | | N | 151 | 152 | 149 | 148 | 148 | 149 | 148 | 148 | 147 | 152 | 150 | 149 |
| | Interactive Software for Production Ordering & Scheduling Capacity | Correlation Coefficient | .274** | .296** | .249** | .281** | .209** | .394** | .327** | .241** | .279** | .215** | 1.000 | .454** |
| | | Sig. (2-tailed) | .001 | .000 | .002 | .000 | .009 | .000 | .000 | .002 | .000 | .008 | . | .000 |
| | | N | 158 | 159 | 157 | 155 | 156 | 156 | 156 | 156 | 155 | 150 | 159 | 156 |
| | Integration of Systems for Interoperability | Correlation Coefficient | .249** | .282** | .236** | .276** | .343** | .277** | .370** | .356** | .375** | .293** | .454** | 1.000 |
| | | Sig. (2-tailed) | .002 | .000 | .003 | .001 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | . |
| | | N | 158 | 159 | 156 | 155 | 155 | 155 | 154 | 154 | 153 | 149 | 156 | 159 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The third hypothesis aims to identify a relationship between organizational size and Industry 4.0 readiness of the organization. According to Ejaz (2022) organizations need to follow a list of prerequisites so that they could assess if they are ready to implement Industry 4.0 technologies or not. The scientific literature also shows that most of the organizations fail to achieve desirable results due to their lack of readiness. The H3 aims to determine if organization size has to play a role in the readiness of an organization for the implementation of the Industry 4.0 technologies. The results are given in detail in table no. 8 Hypothesis no. 3 is given below.

H3: There is a positive influence of organizational size on the organizational readiness for Industry 4.0 technologies.

The results indicates that prerequisites include Financial Capacity and Technical Capabilities have significant positive relationship with organization size independently while the strength is moderate. On the other hand, prerequisites include Installed Certified Hardware, Firewall Data Security, Awareness of Limitations, Manufacturing Knowledge SOPs and Production Ordering & Scheduling Capacity Software have a significant positive relationship with organization size independently but their relationship strength is weak. The prerequisites like System Integration for Interoperability has shown as negative relationship with the organization size. Whereas, Professionally Trained Workforce, High Speed Internet Networking and Thorough Mapping of Operational Processes have a no relationship with the organization size independently.

There are in total 11 perquisites of Industry 4.0 readiness that have been tested against organization size individually and 8 of them show that organization size does have a significant role in the readiness of the Industry 4.0 technologies. The literature on this topic suggests that these prerequisites have to be completed before the implementation of Industry 4.0 technologies otherwise the organizations may not achieve the expected benefits. The result of H3 confirms that organizations have acknowledged the need of the fulfilment of 8 of these prerequisites. Therefore, the study accepts the H3 as there is a positive relationship exists between organization size and Industry 4.0 readiness.

However, all the prerequisites are equally necessary to complete before the implementation of Industry 4.0 technologies. So, it is suggested that organizations are not yet ready enough to implement Industry 4.0 technologies if they fail to complete all the aforementioned prerequisites. There is a greater probability that the implementation of Industry 4.0 technologies would be fruitless. It is important to note that organization size helps in the Industry 4.0 technologies readiness but organization size has nothing to do with the Industry 4.0 technologies implementation. The Industry 4.0 technologies implementation is solely based on the manufacturing and operational requirements of the organization. These requirements are independent of the organization size so, that is why there is no significant

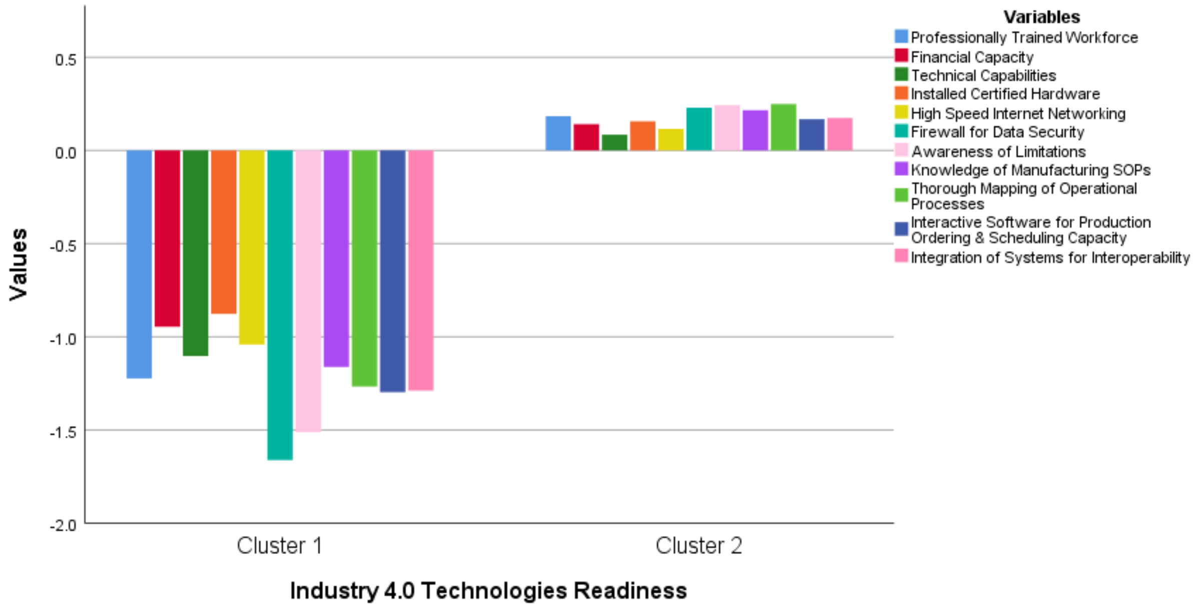


*Figure 13  Cluster Industry 4.0 Technologies Readiness*

relationship between them.

K-Means cluster analysis has been conducted for the prerequisites of Industry 4.0 readiness. The respondents are divided into two clusters after the prerequisites are standardized to attain accurate results. It can be observed from the cluster 1 that responses deviate downwards from the mean while in the cluster 2 the responses are slightly deviated in the upward direction from the mean from the fig. 13. Furthermore, in the table 9, the ANOVA tests have been conducted on the prerequisites to test their significant impact on the cluster Industry 4.0 readiness. The results tell that all the prerequisites have significant impact in differentiating in the clusters. It can be observed form the F values, prerequisites like firewall for data security and awareness of limitations has the most significant impact on the cluster separation.

*Table 9 ANOVA results of Cluster Industry 4.0 Technologies Readiness*

**ANOVA**

| | Cluster | | Error | | | |
|---|---|---|---|---|---|---|
| | Mean Square | df | Mean Square | df | F | Sig. |
| Zscore: Professionally Trained Workforce | 24.656 | 1 | .740 | 125 | 33.327 | .000 |
| Zscore: Financial Capacity | 14.715 | 1 | .858 | 125 | 17.157 | .000 |
| Zscore: Technical Capabilities | 17.565 | 1 | .868 | 125 | 20.238 | .000 |
| Zscore: Installed Certified Hardware | 13.302 | 1 | .855 | 125 | 15.555 | .000 |
| Zscore: High Speed Internet Networking | 16.684 | 1 | .801 | 125 | 20.840 | .000 |
| Zscore: Firewall for Data Security | 44.529 | 1 | .718 | 125 | 61.991 | .000 |
| Zscore: Awareness of Limitations | 38.300 | 1 | .691 | 125 | 55.414 | .000 |
| Zscore: Knowledge of Manufacturing SOPs | 23.628 | 1 | .578 | 125 | 40.886 | .000 |
| Zscore: Thorough Mapping of Operational Processes | 28.623 | 1 | .658 | 125 | 43.501 | .000 |
| Zscore: Interactive Software for Production Ordering & Scheduling Capacity | 26.712 | 1 | .744 | 125 | 35.918 | .000 |
| Zscore: Integration of Systems for Interoperability | 26.652 | 1 | .697 | 125 | 38.256 | .000 |

The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

### 4.2.2 Overall Equipment Effectiveness (OEE)

| | | | Industry 4.0 Implementation | OEE less before Industry 4.0 Implementation |
|---|---|---|---|---|
| Spearman's rho | Industry 4.0 Implementation | Correlation Coefficient | 1.000 | -.050 |
| | | Sig. (2-tailed) | . | .529 |
| | | N | 166 | 160 |
| | OEE less before Industry 4.0 Implementation | Correlation Coefficient | -.050 | 1.000 |
| | | Sig. (2-tailed) | .529 | . |
| | | N | 160 | 160 |

*Table 10a: Change in OEE and Industry 4.0 Technologies*

H4: There is a positive relationship between OEE and the Industry 4.0 technologies.

In manufacturing organizations, OEE is a tool that is being used to measure the performance of the machines. These machines are measured on six different criteria under the OEE. It is believed that the implementation of digital technologies within the context of Industry 4.0 would have a significant positive impact on the OEE of a firm. The results of H4 are given in the table 10a which shows that there is no relationship at all between the OEE and Industry

4.0 technologies. Since the research fails to prove any relationship between any change in OEE and Industry 4.0 technologies. So, change in OEE has been analysed along with the Industry 4.0 technologies independently. The results are shown in the table 10b and it can be

| | | | Industry 4.0 Implementation | Industry 4.0 Adoption Time | Current OEE |
|---|---|---|---|---|---|
| Spearman's rho | Industry 4.0 Implementation | Correlation Coefficient | 1.000 | .129 | .206** |
| | | Sig. (2-tailed) | . | .105 | .009 |
| | | N | 166 | 160 | 160 |
| | Industry 4.0 Adoption Time | Correlation Coefficient | .129 | 1.000 | .257** |
| | | Sig. (2-tailed) | .105 | . | .001 |
| | | N | 160 | 160 | 155 |
| | Current OEE | Correlation Coefficient | .206** | .257** | 1.000 |
| | | Sig. (2-tailed) | .009 | .001 | . |
| | | N | 160 | 155 | 160 |

**. Correlation is significant at the 0.01 level (2-tailed).

*Table 10b: Current OEE and Industry 4.0 Adoption Time*

seen that only one technology Internet of Things, has shown a positive significant relationship with the change in the OEE.

The study further attempts to examine the results depicted in the table 11a. So, the study tests the current OEE with the Industry 4.0 technologies along with its adoption time. The results are portrayed in the table 10b and current OEE has shown a positive significant relationship with both Industry 4.0 technologies implementation and their adoption time. However, the strength of the relationship is weak but it is proven that the time duration of the adoption of Industry 4.0 technologies have an impact on the current OEE. Moreover, the implementation of Industry 4.0 technologies has also shown a relationship with the current OEE. One possible explanation is that since current OEE has been already increased after the implementation of Industry 4.0 technologies however, the extent of increase is slight, so the results in the table 10a are insignificant.

The results in table 10c present a clear picture about the impact of Industry 4.0 technologies over the OEE, as now it is known that not every technology positively impacts the machines to increase the performance. The Internet of Things is the only technology that affects the performance of machines in a positive way. So, now it is also proven that one of the technology that belongs to Industry 4.0 positively affects the OEE. The manufacturing organizations need to digitise their machines with Internet of Things to get enhanced performance. However, Industry 4.0 technologies fail to bring a change in the OEE. Gruber

(2013) argue that a technology by the name of FORCAM based on Industry 4.0 helped to improve OEE of elite companies by 25%. Some of the companies include Daimler (Mercedes-Benz), Audi, BorgWarner and Weir Minerals.

FORCAM is a shop floor management technology which aims to inflate the OEE of companies in the first year of its implementation. This product is aimed at converting a conventional factory into a digital/smart factory and it works on the principles of Industrial Internet of Things (IIoT). FORCAM is a world leading IT solution provider to manufacturing companies in the area of production control and IIoT. They are bringing change to the manufacturing companies by improving their OEE. The results of the dissertation are consistent as only IoT proves a positive relationship with the change in the OEE. The findings from the study and Industry are consistent so it can be deduced from the results that only IoT has the potential to improve OEE in the manufacturing companies.

| | | | OEE less before Industry 4.0 Implementation | ERP | BigData | CloudComputing | 3D Printing | Internet of Things | Simulation | Virtual & Augmented Reality | Robots |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Spearman's rho | OEE less before Industry 4.0 Implementation | Correlation Coefficient | 1.000 | .023 | .040 | .045 | .052 | .157* | .027 | -.052 | .027 |
| | | Sig. (2-tailed) | . | .776 | .615 | .574 | .512 | .047 | .737 | .511 | .737 |
| | | N | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| | ERP | Correlation Coefficient | .023 | 1.000 | .267** | .157* | -.062 | .046 | -.089 | -.102 | -.008 |
| | | Sig. (2-tailed) | .776 | . | .001 | .043 | .424 | .560 | .255 | .190 | .922 |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | BigData | Correlation Coefficient | .040 | .267** | 1.000 | .423** | .022 | .249** | .097 | .142 | .030 |
| | | Sig. (2-tailed) | .615 | .001 | . | .000 | .777 | .001 | .213 | .069 | .702 |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | CloudComputing | Correlation Coefficient | .045 | .157* | .423** | 1.000 | .086 | .335** | .066 | .143 | .133 |
| | | Sig. (2-tailed) | .574 | .043 | .000 | . | .271 | .000 | .401 | .067 | .087 |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | 3D Printing | Correlation Coefficient | .052 | -.062 | .022 | .086 | 1.000 | .221** | .306** | .187* | .006 |
| | | Sig. (2-tailed) | .512 | .424 | .777 | .271 | . | .004 | .000 | .016 | .941 |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Internet of Things | Correlation Coefficient | .157* | .046 | .249** | .335** | .221** | 1.000 | .078 | .147 | .090 |
| | | Sig. (2-tailed) | .047 | .560 | .001 | .000 | .004 | . | .316 | .059 | .246 |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Simulation | Correlation Coefficient | .027 | -.089 | .097 | .066 | .306** | .078 | 1.000 | .290** | .029 |
| | | Sig. (2-tailed) | .737 | .255 | .213 | .401 | .000 | .316 | . | .000 | .709 |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Virtual & Augmented Reality | Correlation Coefficient | -.052 | -.102 | .142 | .143 | .187* | .147 | .290** | 1.000 | .219** |
| | | Sig. (2-tailed) | .511 | .190 | .069 | .067 | .016 | .059 | .000 | . | .005 |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| | Robots | Correlation Coefficient | .027 | -.008 | .030 | .133 | .006 | .090 | .029 | .219** | 1.000 |
| | | Sig. (2-tailed) | .737 | .922 | .702 | .087 | .941 | .246 | .709 | .005 | . |
| | | N | 160 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

*Table 10c OEE and Industry 4.0 Technologies*

The results of the study are concurrent to the findings delivered by the FORCAM as it can been in the table 10c that Internet of Things have a significant weak positive relationship with the change in OEE before and after the implementation of Internet of Things which is a one of the Industry 4.0 technology. The results of the tables 10a, 10b and 10c show that Industry 4.0 technologies as a whole cannot change OEE to a significant level so H4 is stand rejected.

Now Industry 4.0 technologies have tested against the six factors of the OEE. Since OEE fails to establish any relationship with change in OEE so it is also highly likely that results from the OEE variables will also be similar to the previous results. The hypothesis from H4.1 to H4.6 are being developed to see if there is any relationship between Industry 4.0 technologies and OEE six variables exists or not. The hypothesis from H4.1 to H4.6 is given below.

H4.1: There is an inverse relationship between Industry 4.0 technologies and downtime.

H4.2: There is an inverse relationship between Industry 4.0 technologies and setup time.

H4.3: There is an inverse relationship between Industry 4.0 technologies and defective products.

H4.4: There is an inverse relationship between Industry 4.0 technologies and performance loss.

H4.5: There is an inverse relationship between Industry 4.0 technologies and speed losses.

H4.6: There is an inverse relationship between Industry 4.0 technologies and planned/unplanned stoppages.

It can be clearly seen from the table 10a that Industry 4.0 technologies have failed to establish any relationship with the any of the factors of the OEE independently however, this study manages to establish a weak positive relationship between Current OEE and the implementation of Industry 4.0 technologies. It appears to be inconclusive, so therefore, the research rejects the hypothesis from H4.1 to H4.6 as well. However, there are some other interesting positive relationships that the study has unearthed and brought them to light. Decreased downtime has showed a positive significant relationship with decreased setup time and decreased speed losses. Moreover, decreased setup time has shown a positive relationship with decreased defective products. Furthermore, decreased defective products have shown a positive significant relationship with decreased performance losses and decreased planned & unplanned stoppages separately. Additionally, decreased performance losses has a positive significant relationship with decreased speed losses. Also, decreased speed losses have a significant impact on the decreased planned & unplanned stoppages. Likewise, decreased performance losses have a significant impact on the decreased planned & unplanned stoppages.

The research tries to determine the causes of the failure of hypothesis from H4.1 to H4.6 and in this regard, further testing has been done and results can be seen in the table 11. The results show that the adoption time of Industry 4.0 technologies has a significant weak positive relationship with the decrease in the performance loss. Performance losses occurs due to idling and minor stoppages which are caused when machines are idle or temporary malfunctioned. These results are depicting a clear picture now. OEE variables take time to improve and provide results to the significant level. Hedman et al. (2016) mention that even though OEE is well defined in the literature however, companies tend to interpret the loss factors in OEE in various ways. Moreover, extremely high level of accuracy in data collection is also required in order to attain fair results. It is also important to mention that surrounding environment and the actions of the machine operators also affect the OEE. Production planning and control policies of the companies can handle these kind of issues in a better manner.

*Table 11: Industry 4.0 Adoption Time and OEE variables*

| | **Industry 4.0 Adoption Time** | |
|---|---|---|
| **Decreased Downtime** | Correlation Coefficient | .048 |
| | Sig. (2-tailed) | .555 |
| | N | 156 |
| **Decreased Setup time** | Correlation Coefficient | .042 |
| | Sig. (2-tailed) | .612 |
| | N | 151 |
| **Decreased Defective Products** | Correlation Coefficient | -.031 |
| | Sig. (2-tailed) | .701 |
| | N | 157 |
| **Decrease in Performance Loss** | Correlation Coefficient | **.204*** |
| | Sig. (2-tailed) | **.011** |
| | N | **156** |
| **Decreased Speed Losses** | Correlation Coefficient | -.001 |
| | Sig. (2-tailed) | .995 |
| | N | 155 |
| **Decreased Planned & Unplanned Stoppages** | Correlation Coefficient | -.044 |
| | Sig. (2-tailed) | .589 |
| | N | 156 |

**Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).*

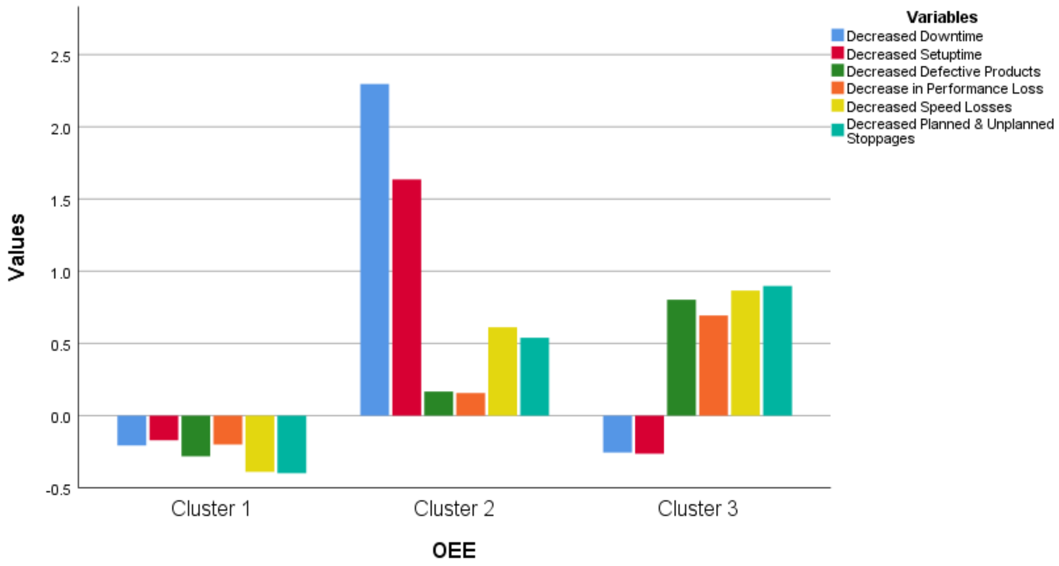


*Figure 14: Cluster OEE*

| | Cluster | | Error | | | |
|---|---|---|---|---|---|---|
| | Mean Square | df | Mean Square | df | F | Sig. |
| Decreased Downtime | 40.152 | 2 | .506 | 145 | 79.353 | .000 |
| Decreased Setuptime | 21.358 | 2 | .658 | 145 | 32.468 | .000 |
| Decreased Defective Products | 15.360 | 2 | .792 | 145 | 19.405 | .000 |
| Decrease in Performance Loss | 10.436 | 2 | .882 | 145 | 11.827 | .000 |
| Decreased Speed Losses | 23.245 | 2 | .718 | 145 | 32.370 | .000 |
| Decreased Planned & Unplanned Stoppages | 24.013 | 2 | .662 | 145 | 36.292 | .000 |

The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

*Table 12: ANOVA results of Cluster OEE*

The OEE variables are divided into 3 clusters by using K-Means clustering after standardizing the variables in order to attain accurate results. In the fig 14, cluster one shows that the values are slightly below the mean, however, values are above the mean in the cluster 2. On the other hand, in the cluster 3, decreased downtime and decreased setup time are slightly below the mean while others are higher than the mean value. In the table 12, it can be seen that all the variables have a significant impact on the cluster OEE. The F values indicate that decreased down time has the highest level of significant impact on the clusters while decreased set up time, decreased speed losses and decreased unplanned/planned stoppages have moderate levels of significance. However, decreased defective products and decreased performance loss has the lowest significant influence on the clusters.

### 4.2.3 Competitiveness

One of the major reasons why organizations implement Industry 4.0 technologies is to achieve manufacturing competitiveness at the organization level. The hypotheses from H5.1 to H5.9 aim to determine the significant impact of Industry 4.0 on competitiveness and different variables. However, H5 is aimed to determine if there is any significant impact of Industry 4.0 technologies on the competitiveness overall.

The hypotheses ranging from H5 and H5.1 to H5.9 are given below.

H5: There is a significant impact of Industry 4.0 technologies on competitiveness

H5.1: There is a significant impact of Industry 4.0 technologies on reduction in resource usage

H5.2: There is a significant impact of Industry 4.0 technologies on reduction in production cost

H5.3: There is a significant impact of Industry 4.0 technologies on increased manufacturing capabilities

H5.4: There is a significant impact of Industry 4.0 technologies on increased R &D

H5.5: There is a significant impact of Industry 4.0 technologies on increased product quality

H5.6: There is a significant impact of Industry 4.0 technologies on increase mass customization

H5.7: There is a significant impact of Industry 4.0 technologies on increased operational efficiency

H5.8: There is a significant impact of Industry 4.0 technologies on flexible manufacturing process

H5.9: There is a significant impact of Industry 4.0 technologies on more flexible product design

The linear regression analysis has been conducted and it can be observed from the table 13 that there is a significant impact of Industry 4.0 technologies on competitiveness. The results shows p-value = 0.05 so we accept H5 and conclude that Industry 4.o significantly impact competitiveness and it's dependent on the Industry 4.0 technologies.

*Table 13: Industry 4.0 Technologies Implementation & Competitiveness Variables*

| | B | t | p-value |
|---|---|---|---|
| **Industry 4.0 Technologies** | -.596 | -2.844 | **.005** |
| | **R Square** | **F (1, 148)** | |
| | .052 | 8.090 | |
| a. Dependent Variable: Competitiveness | | | |

**p-value ≤ 0.05*

So, each of the Industry 4.0 technology has been also tested with each competitiveness variable independently to dig deep to see if there is any significant impact of each of the industry 4.0 technology on any of the competitiveness variable. The results can be seen in the table 15 below. The results in the table 14 shows that none of the Industry 4.0 technologies has an impact on the reduction in resource usage, reduction, increased manufacturing capabilities, increased product quality and increased operational efficiency. ERP seems to have a significant impact on the reduction in the production cost. The results also show that Big Data and Robots have also a significant impact on the increased R & D. It can also be seen that Robots also have a significant impact on the increased mass customisation. ERP, Cloud Computing, 3D printing, Simulation and Robots have significant impact on the flexible manufacturing process. Last but not the least, 3D printing and Robots also have significant impact over the more flexible product design.

The overall picture of table 14 depicts that Industry 4.0 technologies have a meaningful impact on flexible manufacturing processes and more flexible product designs. It can be deduced that if a manufacturing firm wants to build competitiveness based on these variable, the firm will most likely to be successful. It can also be observed from the table 13 that the dissertation has also accepted the p-values between 0.05 and 0.1. It is more likely that these variables have a weak significant impact and it cannot be ruled out as insignificance.

*Table 14: Industry 4.0 Technologies Implementation & Competitiveness Variables*

| | **Reduction in Resources Usage** | | | **Reduction in Production Cost** | | | **Increased Manufacturing Capabilities** | | | **Increased R&D** | | | **Increased Product Quality** | | | **Increased Mass Customisation** | | | **Increased Operational Efficiency** | | | **Flexible Manufacturing Process** | | | **More Flexible Product Design** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **B** | **t** | **p-value** | **B** | **t** | **p-value** | **B** | **t** | **p-value** | **B** | **t** | **p-value** | **B** | **t** | **p-value** | **B** | **t** | **p-value** | **B** | **t** | **p-value** | **B** | **t** | **p-value** | **B** | **t** | **p-value** |
| **ERP** | -.026 | -2.15 | .830 | -.278 | -2.091 | **.038** | -.155 | -1.09 | .275 | .155 | .836 | .404 | -.036 | -.262 | .794 | -.069 | -.308 | .759 | -.064 | -.424 | .672 | .448 | 2.22 | **.028** | -.032 | -.087 | .931 |
| **Big Data** | .010 | .084 | .933 | .045 | .357 | .722 | -.072 | -.528 | .598 | -.309 | -1.74 | **.084** | .096 | .726 | .469 | .167 | .775 | .440 | .043 | .300 | .764 | -.058 | -.296 | .767 | .522 | 1.48 | .139 |
| **CC** | -.045 | .355 | .723 | -.150 | -1.113 | .268 | -.143 | -.995 | .321 | .063 | .333 | .740 | .020 | .143 | .887 | -.011 | -.050 | .960 | -.036 | -.234 | .816 | -.455 | -2.21 | **.028** | -.480 | -1.29 | .197 |
| **3DP** | -.046 | .388 | .699 | -.053 | -.425 | .671 | -.069 | -.520 | .604 | -.192 | -1.10 | .270 | .082 | .628 | .531 | -.207 | -.992 | .323 | -.121 | -.868 | .387 | -.564 | -2.99 | **.003** | -1.088 | -3.20 | **.002** |
| **IoT** | .022 | .193 | .848 | .190 | 1.585 | .115 | -.049 | -.381 | .703 | -.150 | -.887 | .377 | -.205 | -1.615 | .108 | -.130 | -.644 | .521 | .081 | .595 | .553 | -.143 | -.784 | .434 | .424 | 1.28 | .201 |
| **Simulation** | -.067 | -.529 | .597 | -.146 | -.1.092 | .277 | -.117 | -.826 | .410 | -.005 | -.029 | .977 | .176 | 1.245 | .215 | -.264 | -1.17 | .242 | .109 | .723 | .471 | -.372 | -1.83 | **.068** | .308 | .884 | .401 |
| **V/A Reality** | -.050 | -.301 | .764 | -.053 | -.306 | .760 | .003 | .014 | .989 | .158 | .660 | .510 | .021 | .119 | .905 | -.411 | -1.42 | .157 | -.117 | -.607 | .545 | .408 | 1.56 | .119 | -.009 | -.020 | .984 |
| **Robots** | .029 | .248 | .804 | .067 | .533 | .595 | -.024 | -.179 | .858 | -.386 | -2.18 | **.031** | -.040 | -.303 | .762 | -.537 | -2.53 | **.012** | .098 | .692 | .490 | -.337 | -1.76 | **.080** | -.784 | -2.27 | **.024** |
| | **R Sq.** | **F (8, 151)** | | **R Sq.** | **F (8, 149)** | | **R Sq.** | **F (8, 150)** | | **R Sq.** | **F (8, 150)** | | **R Sq.** | **F (8, 149)** | | **R. Sq.** | **F (8, 150)** | | **R.Sq.** | **F (8, 151)** | | **R. Sq.** | **F (8, 150)** | | **R.Sq.** | **F (8, 150)** | |
| | .006 | .105 | | .061 | 1.217 | | .044 | .855 | | .074 | 1.495 | | .037 | .710 | | .105 | 2.209 | | .014 | .264 | | .198 | 4.631 | | .116 | 2.464 | |

a. Reduction in Resources Usage b. Reduction in Production Cost c. Increased Manufacturing Capabilities d. Increased R&D e. Increased Product Quality f. Increased Mass Customisation g. Increased Operational Efficiency h. Flexible Manufacturing Process i. More Flexible Product Design

**p-value ≤ 0.05*

Simulation also establishes a negative relationship with increased mass customization and flexible manufacturing process while it fails to establish any relationship with others. Virtual & Augmented Reality has established a negative relationship with increased mass customization. Though, they fail to prove any relationship with other variables. Collaborative Robots have established a negative relationship with increased R&D, increased mass customization and more flexible product designs independently. However, it fails to establish any relationship with the other variables. Based on the discussion above and results, we can conclude that H5.4, H5.6, H5.8 and H5.9 are accepted.

K-Means cluster analysis on the competitiveness variables has been conducted and it can be seen in the fig. 15. The competitiveness variables have been standardized first to gather more accurate results. It can be observed from the graph that there is least deviation in variables in the cluster 1. However, variables is most deviation has to be found the cluster 2 while cluster 3 has a moderate level of deviation among the variables.

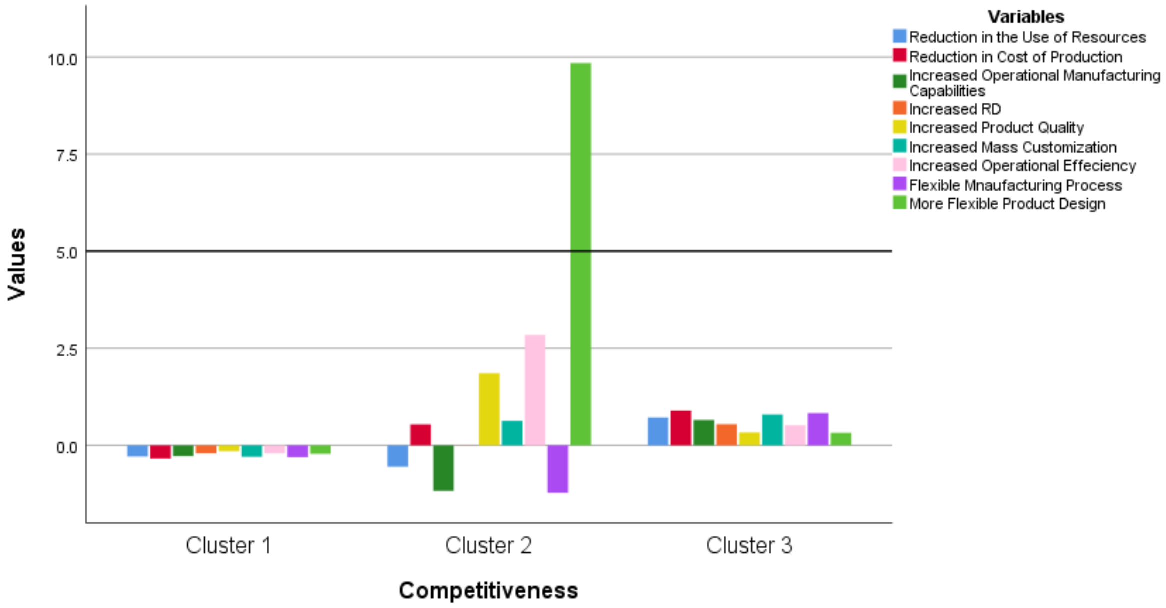


*Figure 15 Cluster Competitiveness*

The ANOVA table expresses the significance of the variables on the competitiveness cluster. It can be seen in the table 16, that all the variables have a significant impact on the cluster competitiveness while increased product quality does not have a significant impact in the cluster competitiveness. The F value tells us the more flexible design has the most significant impact on the cluster separation as compared to all other variables.

*Table 15: ANOVA results of Cluster Competitiveness*

**ANOVA**

| | Cluster | | Error | | | |
|---|---|---|---|---|---|---|
| | Mean Square | df | Mean Square | df | F | Sig. |
| Zscore: Reduction in the Use of Resources | 15.086 | 2 | .797 | 147 | 18.935 | .000 |
| Zscore: Reduction in Cost of Production | 22.896 | 2 | .730 | 147 | 31.372 | .000 |
| Zscore: Increased Operational Manufacturing Capabilities | 13.592 | 2 | .804 | 147 | 16.907 | .000 |
| Zscore: Increased RD | 8.309 | 2 | .891 | 147 | 9.330 | .000 |
| Zscore: Increased Product Quality | 5.203 | 2 | .898 | 147 | 5.795 | .004 |
| Zscore: Increased Mass Customization | 17.808 | 2 | .799 | 147 | 22.283 | .000 |
| Zscore: Increased Operational Effeciency | 11.792 | 2 | .872 | 147 | 13.528 | .000 |
| Zscore: Flexible Mnaufacturing Process | 19.863 | 2 | .720 | 147 | 27.594 | .000 |
| Zscore: More Flexible Product Design | 53.163 | 2 | .331 | 147 | 160.655 | .000 |

The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

## 4.3 Impact of the Results on the Literature

The hypothesis from H1 to H3 confirms that there is a strong relationship between the organization size and Industry 4.0 readiness, adoption and implementation of the technologies. These results are in aligned with the prior studies that large organizations tend to adopt and implement Industry 4.0 technologies sooner than their fellow SMEs due to availability of resources and workforce. The nature of Industry 4.0 technologies is complicated and it demands a thorough analysis if an organization's size in terms of workforce and productivity. Even within the manufacturing sector, the broad spectrum of manufacturing areas complicates the use of the technologies at times. Although organization size is not part of the primary literature it is important to analyse if organization size can play an important role in the adoption and implementation of Industry 4.0 technologies or not. In this case, organizations need to be big enough to implement industry 4.0 technologies so that it could be translated into sustainable competitiveness.

OEE is one important metric to measure equipment effectiveness in a manufacturing environment. It is also vital to obtain operational competitiveness for a manufacturing organization. The results of the thesis indicate that there is no correlation between Industry 4.0 and OEE. Moreover, the thesis failed to establish any correlation among Industry 4.0 and any of the variables of the OEE. Hence rejecting hypothesis from H4, g4.1 to H4.6 in accordance with the results is the only option. However, these results do not align with the present literature. The literature suggests that the technology infusion should improve operational competitiveness. The closer look at the results reveals that the Industry 4.0 technologies do have a significant correlation with the OEE variables individually. However, this correlation is not strong and significant enough to make an overall impact on the results. One possible reason might the sample size is based on a broad spectrum of the manufacturing firms within the manufacturing sector.

The literature also focuses on the challenges and limitations that OEE brings with it towards the manufacturing organizations. There are several internal and external factors that can limit the OEE even after the implantation of the Industry 4.0 technologies. A bottleneck in one single piece of equipment can slowdown the whole production line and cause the unplanned stoppages, performance loss and speed loss. If one variable is disturbed significantly, it can bring down the whole OEE percentage and it can lose the significant change that one is hoped.

The regression analysis has been done to test the hypothesis H5, H5.1 to H5.9 shows that overall competitiveness is dependent on the Industry 4.0 technologies. It does perfectly align with the literature reviewed as well. The thorough analyses of the data reveal which variables have the impact from which type of Industry 4.0 technology. The flexible manufacturing process is the one which shows the most significant impact of Industry 4.0 technologies in this regard. It can be deduced that manufacturing firms under question are more interested in developing operational competitiveness in terms of flexible manufacturing process. This also explains why operational efficiency has not impacted by the Industry 4.0 at all as it is also related to the OEE. The results related to OEE also seem to be insignificant as well.

# 5 Recommendations & Suggestions

The study has devised some suggestions and recommendations for the managers working in the manufacturing organizations in the light of the findings of this study. This study has also devised few suggestions and recommendations for the policy makers or the top management of the manufacturing organizations. These recommendations are related to the manufacturing practices in the organizations and their approach towards the improvement in the context of Industry 4.0 implementation.

## 5.1 Recommendations for Managers

The results of the thesis have shown so far that organizations size, Industry 4.0 readiness of the organization play an instrumental role in achieving a significant OEE score and operational competitiveness. There are several factors that are as crucial as the implementation of Industry 4.0 technologies. There are some recommendations formulated by the thesis in the light of the results.

- Managers are required to adopt best suited technologies for their manufacturing needs as proven in the results shown in table 7.
- The financial capacity of the organizations has to be developed so that organizations could implement Industry 4.0 technologies. These technologies require large investments as it is also proven in H3. Long terms strategies can help organizations to allocate funds for this purpose.
- Technical capabilities are another major concern for the managers. When a technology helps to increase the volume of the production then other related departments should be equipped to handle the inflated production otherwise it would create a bottleneck in the production line.
- Managers are required to address the issue of technical capabilities not only by purchasing modern equipment but also through purchasing software packages to run the equipment.
- Managers should do a thorough mapping of manufacturing process based on results given in table 8. It should be done to decrease the operational limitations.
- Managers need to develop interoperability in the operational processes after the implementation of Industry 4.0 technologies based on results given in table 8

- Managers should realize the fact that OEE will not improve by just incorporating Industry 4.0 technologies. Study suggests that IoT is best recommended to improve OEE for the manufacturing organizations.
- Managers should know that there might not be a significant relationship between IoT technologies and six dimensions of OEE separately but collectively there is proven significant relationship based on the results shown in table 10c. So, managers are advised to improve all the dimensions of OEE so that a significant change in OEE could be seen.
- The study proves H5 as there is a significant impact of Industry 4.0 technologies over competitiveness. The managers should focus on the flexible manufacturing process and flexible product designs to obtain competitiveness within their manufacturing environment.

## 5.2 Limitations of the Study

A scientific research is exhaustive in nature and number of obstacles is part of every research project. In the scientific research when it is interdisciplinary in nature and it involves valuable information from the industry then numbers of limitations may increase to the drastic level. In some cases, number of limitations is greater in number but in some cases, number of cases is few but they are hard to cope and there are chances that they might affect the quality of the study. The topic of Industry 4.0 is still an evolving topic and new dimensions related to the Industry 4.0 are yet to be explored. There is always a room for future researchers to take this research one step ahead for the betterment of academia and Industry. This study was first of its nature where impact of Industry 4.0 technologies has been analysed along with various factors on OEE and manufacturing competitiveness.

The managers are still sceptical about the Industry 4.0. There is a between the university scholars and the managers working in the industry. This knowledge gap also created limitations which can only be reduced by knowledge sharing. On the other hand, there are several ways to cope with the limitations to ensure the integrity of the research to the optimum level. This study also has few limitations and author has done the best job to his abilities to conduct the research. A list of notable limitations is given below.

- Online questionnaire has restricted reach to the respondents as it causes low response rate.

- Questionnaire with adequate size is used to reach respondents online, long questionnaire discourages the response rate.
- Long questionnaires with high response rate could have helped to gather more information in depth.
- UK manufacturing sector is chosen conduct my research to eliminate the language barriers and developed few connections as well in the manufacturing organizations with the help of friends and family living in the UK. In this regard, a survey from German manufacturing sector in local language would have been useful to gather data and would have provided an insightful comparative study.
- Lack of trust and willingness was also major limitation in the research process. Several managers did not even open the link just because they did not trust it since they thought it might be a scam or something else. Upon realizing the issue, I had to assure them that they can trust this link as it will help me if they fill out the online questionnaire.
- The manager's credibility was another limitation so, the study promised complete anonymity to the managers. It helped to get them filled the questionnaire to the best of their knowledge and experience.

## 5.3 Contributions of the Study

The thesis is first of its than that has emphasized on the importance of the Industry 4.0 technologies readiness and its impact on the organizations in terms of digital transformation, OEE and manufacturing competitiveness in the UK manufacturing sector. This study has contributed by offering its theoretical and methodological findings through the research. These findings are so important that they prove to be the crucial for the managers working in the organizations as it will clear any myths about technology or Industry 4.0. There are also eye-opening results for researchers also as several concepts that we had developed about Industry 4.0 and its implications have been proven otherwise and new information has come to light in this field of research.

In the empirical findings, first of all it has been noted that the size of the organization plays a significant role in the adaptation of various Industry 4.0 technologies. It has also been observed that size of the organization has also an impact of the degree of the readiness of the organizations in order to implement Industry 4.0 technologies. Large size organizations have a greater chance to achieve the required level of readiness as compared to small or medium sized organizations. The thesis has proved the significance of Industry 4.0 readiness by the fulfilment of the prerequisites. There is a positive correlation between large size organizations and Industry 4.0 readiness prerequisites. The empirical research also proves that one of the Industry 4.0 technology which is IoT have a significant positive impact on the OEE. Since OEE measures the equipment efficiency and improvement in OEE can lead to operational efficiency. In the theoretical findings it is proven that technology did bring competitiveness in terms of operational efficiency. The results have showed that Industry 4.0 technologies have established a significant impact on competitiveness. Further analyses have revealed that flexible manufacturing process and flexible product design. It also supports the theoretical findings that the competitiveness based on Industry 4.0 only will diminish over time so; it should be implemented along with society, industry, government and academia to achieve sustainable competitiveness. The manufacturing competitiveness goals may vary across the sector and also within the manufacturing sector. This study enlightens us with the fact that the organizations that have acquired Industry 4.0 technologies recently have their focus on flexible manufacturing processes and flexible product designs.

The dissertation which is titled "Transformative Impact of Industry 4.0 Technologies on the UK Manufacturing Sector" aims to present new avenues and dimensions in this research field. The theoretical and the empirical findings of the study provides a way forward for potential future studies in this research domain and help the researchers in the future.

# 6 Conclusion

Industry 4.0 is termed as the fourth industrial revolution that has been digitally transforming the world since its inception in 2011. It is a concept originated in Germany and now few other countries have also started to the first step in the age of digital transformation by initiating their own initiatives. The automations of industrial equipment to enhance operational efficiency along with competitiveness, flexible production process and OEE is an ultimate goal of several manufacturing organizations by the adaptation of Industry 4.0 technologies.

The digital transformation is significantly dependent on the readiness of the organizations regarding Industry 4.0. There is a list of prerequisites that are extracted after the extensive literature review. These prerequisites are necessary for every organization to follow as they will ensure that the organization is ready to implement the Industry 4.0 technologies. A theoretical model has been developed to measure the readiness of the organization in order to implement Industry 4.0 technologies. The empirical results of the study have also proved that these prerequisites are important for the organizations in order to implement Industry 4.0 technologies. Prerequisites like financial capacity, technical capability, certified hardware, data security, awareness of limitations, knowledge of manufacturing SOPs, production planning, schedule capacity and integration of systems for interoperability have proven vital in organizational readiness. When organizations develop the strategy to implement Industry 4.0 technologies, they must work on these prerequisites first and evaluate their degree of readiness with the help of the theoretical model. It will help the organizations to make profitable decisions.

The first and initial goal of the organizations after the successful implementation of Industry 4.0 is to increase the OEE of the manufacturing facility. The increase in demand and other factors force machines to work for long hours that also increases scheduled and unscheduled stoppage times for maintenance. It reduces the effectiveness of equipment as well by consuming more resources than they should and producing defective products. This all leads to low OEE and this problem can only be resolved through the implementation of the right Industry 4.0 technologies. OEE is a performance measurement tool that an organization uses to evaluate the effectiveness of their equipotent. Literature and empirical evidence have showed that only IoT has the potential to affect the OEE significantly. Organizations should implement IoT based technologies to enhance their OEE if it is their goal for their manufacturing facilities. Higher OEE might be used as a competitive edge however, not for long until their competitors does the same and, hence eliminating their competitive edge.

The digitalization of manufacturing is important to achieve sustainable manufacturing for the organizations. There are numerous challenges related to manufacturing that are being faced by the organizations these days and these challenges are mostly related to operational efficiency, OEE, competitiveness , flexible manufacturing process and flexible product designs. There is no doubt that the Industry 4.0 technologies help organizations greatly in the domain of manufacturing and this is the basic aim of this study to explore all of these above said dimensions in terms of literature review and the empirical evidence. The research in this field has given us some unexpected results. The expectations were based on the literature review findings. However, empirical data contradicts some of the existing literature and new results have been contributed in this research field related to Industry 4.0 and its impacts OEE. OEE is a measurement mechanism that is being used for maintenance and/or performance improvement of the equipment. There are several external and internal factors that might hinder the results and

The study has also presented theoretical models for degree of digital readiness for organizations and competitiveness of organizations based on the operational efficiency. These are valuable contributions to the existing literature. Competitiveness is a wide subject itself however, this study explores the aspects of competitiveness related to Industry 4.0 technologies. Knowledge management is a key to find a perfect balance and some call it a strategic fit for an organization which can only be achieved through years to research and collaboration with other institutions like society, government, environment, industry and academia. It is known as Quintuple Helix model and the theoretical model presented by the study suggests that it can help to gain sustainable competitiveness. This study has its own limitations as it was impossible to measure the impact of Industry 4.0 on the government, environment, society and academia, so only industry was included in the empirical study. The empirical data shows Industry 4.0 technologies can bring any competitiveness. The empirical results have shown a significant impact of Industry 4.0 technologies and some of the competitiveness variables.

Organizations wish to achieve operational competitiveness which was believed for a long time that operational competitiveness is hard to imitate by the competitors as compared to competitiveness based on products, prices or marketing. It is believed that knowledge management can play a vital role for organizations to achieve manufacturing competitiveness. Organizations need to develop knowledge centres in their organizations connected with academia, society and the government.

A single organization cannot bring competitiveness on its own but it will require clustering, resources and policies to build the foundation of its competitiveness. A group of companies working in the same industry located in the same region shares the R&D which can bring competitiveness. It can only happen when governments support these organizations to work in close proximity. Similarly, abundances of resources available to an organization can help an organization build competitiveness. In the last, the government policies can help organizations to develop a unique competitive edge over others. In some cases, these competitive edges can be eroded over time. However, if they are developed together with the support of other institutions like academia and society then sustainable competitiveness can be achieved.

One of the advantages that can be gained by the manufacturing organizations is to produce more flexible products. Flexible products are the products which offer multiple utility for the consumers as compared to the standard product which only provides a single utility. The study has established a significant impact of Industry 4.0 technologies on flexible product manufacturing. Flexible Manufacturing Process is closely associated with flexible products. Industry 4.0 technologies have a significant impact on flexible product manufacturing process. Flexible Manufacturing Process is the most sought competiveness variable among the manufacturing organisations in the UK manufacturing sector.

The findings of this study have laid a solid foundation for the researchers in the future related to the role of Industry 4.0 technologies and their implications in the domain of manufacturing. The idea of smart manufacturing and smart factory are attractive hence plenty of research has been done in the research field. It is an interdisciplinary field and countless variables and issues come with Industry 4.0. Organizations can consider it as an opportunity and adopt it accordingly. Like every technology there are several positives attached to Industry 4.0 and these positives should be utilities to the maximum level possible. However, the Industry 4.0 itself can benefit neither individuals nor organizations. Individuals and organizations have to upgrade their knowledge basis, new business models and new organizational structures have to adopt to implement Industry 4.0.

Organizations need to prove that they are ready for the change and can adopt industry 4.0 technologies. They need to choose best suited technology to improve OEE and manufacturing competitiveness cannot be achieved simply by adopting a new technology. A management strategy has to be developed by the managers and every organization needs to find their own strategic fit. This is the only way to develop a sustainable competitiveness otherwise same technology can be bought by the competitors as well. Similarly flexible products and flexible manufacturing can be done by using Industry 4.0 however; these products can become outdate by the competitors over time.

In short, Industry 4.0 technologies are a wide and evolving concept since its inception. It is a multi-disciplinary concept so collaborations of academia and industry are important to explore new dimensions of this concept. The contributions of the study titled "The impact of Industry 4.0 technologies on the manufacturing industry" provide researchers new ideas for their future research in the light of empirical evidence provided by this study.

# 7 References


- Abdirad, M., Krishnan, K., & Gupta, D. (2020). A two-stage metaheuristic algorithm for the dynamic vehicle routing problem in Industry 4.0 approach. *Journal of Management Analytics,* 8(1), 69-83. https://doi.org/10.1080/23270012.2020.1811166
- Acs, Z. J., & Audretsch, D. B. (1988). Innovation and firm size in manufacturing. *Technovation*, 7(3), 197–210. https://doi.org/10.1016/0166-4972(88)90020-x
- Acs, Z., Song, A., Szerb, L., Audretsch, D., & Komlósi, É. (2021). The evolution of the global digital platform economy: 1971–2021. *Small Business Economics,* 57(4), 1629-1659. https://doi.org/10.1007/s11187-021-00561-x
- Ahmad, M. M. (2018). Assessment methodology for competitive manufacturing. *Procedia Manufacturing*, 17, 843–851. https://doi.org/10.1016/j.promfg.2018.10.136
- Ahmed, M. H. (2013). OEE can be your key. *Industrial Engineer*, 45(8), 43–48.
- Akoglu, H. (2018). User's Guide to Correlation Coefficients. *Turkish Journal of Emergency Medicine*, *18*(3), 91–93. https://doi.org/10.1016/j.tjem.2018.08.001
- Akpinar, M. (2020). The fit of competitive strategies and firm-specific advantages with country-specific advantages in explaining manufacturing location choices. *Competitiveness Review: An International Business Journal*, 30(3), 245-268. https://doi.org/10.1108/cr-12-2018-0082
- Aleš, Z., Pavlů, J., Legát, V., Mošna, F., & Jurča, V. (2019). Methodology of overall equipment effectiveness calculation in the context of Industry 4.0 Environment. *Eksploatacja i Niezawodność – Maintenance and Reliability*, 21(3), 411–418. https://doi.org/10.17531/ein.2019.3.7
- Alford, D., Sackett, P. and Nelder, G. (2000). Mass customisation — an automotive perspective. *International Journal of Production Economics*, 65(1), 99-110. https://doi.org/10.1016/S0925-5273(99)00093-6
- Alhassan, E., Schillo, R., Lemay, M., & Pries, F. (2017). Research Outputs as Vehicles of Knowledge Exchange in a Quintuple Helix Context: The Case of Biofuels Research Outputs. *Journal of The Knowledge Economy*, 10(3), 958-973. https://doi.org/10.1007/s13132-017-0507-8
- Allen, I. E., & Seaman, C. A. (2007). Likert scales and data analyses. *Quality progress*, *40*(7), 64-65.

- Alptekinoğlu, A. and Ramachandran, K. (2019). Flexible Products for Dynamic Preferences. Production and Operations Management, 28 (6), 1558-1576. https://doi.org/10.1111/poms.12990
- Alsmadi, M., Almani, A., & Jerisat, R. (2012). A comparative analysis of Lean practices and performance in the UK manufacturing and service sector firms. *Total Quality Management & Business Excellence*, 23(3–4), 381–396. https://doi.org/10.1080/14783363.2012.669993
- Annarelli, A., Battistella, C., Nonino, F., Parida, V., & Pessot, E. (2021). Literature review on digitalization capabilities: Co-citation analysis of antecedents, conceptualization and consequences. *Technological Forecasting & Social Change*, 166, 120635. https://doi.org/10.1016/j.techfore.2021.120635
- Aranguren, M., & Magro, E. (2020). How can universities contribute to regional competitiveness policy-making?. *Competitiveness Review: An International Business Journal,* 30(2), 101-117. https://doi.org/10.1108/cr-11-2018-0071
- Ark, B. van. (2016). The Productivity Paradox of the New Digital Economy. *International Productivity Monitor*, 31, 3–18.
- Arnett, D., Sandvik, I. & Sandvik, K. (2018). Two paths to organizational effectiveness – Product advantage and life-cycle flexibility. Journal of Business Research, 84, 285-292. https://doi.org/10.1016/j.jbusres.2017.11.010
- Arrona, A., Franco, S., & Wilson, J. (2020). Public innovation through governance in place-based competitiveness policymaking. *Competitiveness Review: An International Business Journal*, 30(2), 119-136. https://doi.org/10.1108/cr-03-2018-0023
- Asadi, N., Jackson, M. and Fundin, A. (2019). Implications of realizing mix flexibility in assembly systems for product modularity—A case study. Journal of Manufacturing Systems, 52, 13-22. https://doi.org/10.1016/j.jmsy.2019.04.010
- Atkin, D., Chaudhry, A., Chaudry, S., Khandelwal, A., & Verhoogen, E. (2017). Organizational Barriers to Technology Adoption: Evidence from Soccer-Ball Producers in Pakistan*. *The Quarterly Journal of Economics*, 132(3), 1101-1164. https://doi.org/10.1093/qje/qjx010
- Azeem, M., Ahmed, M., Haider, S., & Sajjad, M. (2021). Expanding competitive advantage through organizational culture, knowledge sharing and organizational innovation. *Technology in Society*, 66, 101635. https://doi.org/10.1016/j.techsoc.2021.101635

- Bag, S., Pretorius, J., Gupta, S. & Dwivedi, Y. (2021). Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities. *Technological Forecasting and Social Change*, 163, p.120420.https://doi.org/10.1016/j.techfore.2020.120420
- Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics*, 229, 107776. https://doi.org/10.1016/j.ijpe.2020.107776
- Bellini, P., Cenni, D., Mitolo, N., Nesi, P., Pantaleo, G., & Soderi, M. (2022). High level control of chemical plant by industry 4.0 solutions. *Journal of Industrial Information Integration*, 26, 100276. https://doi.org/10.1016/j.jii.2021.100276
- Bessant, J., & Francis, D. (1999). Using learning networks to help improve manufacturing competitiveness. *Technovation*, 19(6-7), 373-381. https://doi.org/10.1016/s0166-4972(99)00025-5
- Bettiol, M., Capestro, M., De Marchi, V., Di Maria, E., & Sedita, S. (2020). Industrial districts and the fourth industrial revolution. *Competitiveness Review: An International Business Journal*, 31(1), 12-26. https://doi.org/10.1108/cr-12-2019-0155
- Bhade, S., & Hegde, S. (2020). Improvement of overall equipment efficiency of machine by SMED. Materials Today: Proceedings, 24, 463–472. https://doi.org/10.1016/j.matpr.2020.04.298
- Bilgeri, D., Wortmann, F., & Fleisch, E. (2017). How Digital Transformation Affects Large Manufacturing Companies' Organization. In *Thirty Eighth International Conference on Information Systems* (pp. 1-9). South Korea.
- Bonvoisin, J., Halstenberg, F., Buchert, T. & Stark, R. (2016). A systematic literature review on modular product design. Journal of Engineering Design, 27(7), 488-514. https://doi.org/10.1080/09544828.2016.1166482
- Boone, H. N., & Boone, D. A. (2012). Analyzing Likert Data. *Journal of Extension*, *50*(2), 1–5.
- Boonman, H., Hagspiel, V., & Kort, P. (2015). Dedicated vs product flexible production technology: Strategic capacity investment choice. *European Journal of Operational Research*, 244(1), 141-152. https://doi.org/10.1016/j.ejor.2015.01.007

- Bradley, R., I. S. Jawahir, F. Badurdeen, & Rouch, K. (2018). ‘A total life cycle cost model (TLCCM) for the circular economy and its application to post-recovery resource allocation.’ *Resources, Conservation and Recycling* 135, 141–149
- Brien, P. (2024a, January 2). *Manufacturing: Key economic indicators*. House of Commons Library. https://commonslibrary.parliament.uk/research-briefings/sn05206/
- Brien, P. (2024b, January 4). *Service industries: Key economic indicators*. House of Commons Library. https://commonslibrary.parliament.uk/research-briefings/sn02786/
- Bu, L., C. Chen, K. Ng, P. Zheng, G. Dong, & Liu, H. (2021). ‘A user-centric design approach for smart product-service systems using virtual reality: A case study.’ *Journal of Cleaner Production,* 280, 124413.
- Büchi, G., Cugno, M. & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological Forecasting and Social Change*, 150, p.119790.https://doi.org/10.1016/j.techfore.2019.119790
- Canco, I. (2017). The Contribution Of Decision Making Methods To Business Success (Ph.D.). University of Pécs.
- Cao, D., Wang, Y., Berkeley, N., & Tjahjono, B. (2021). Configurational conditions and Sustained Competitive Advantage: A fsQCA approach. *Long Range Planning*, 102131. https://doi.org/10.1016/j.lrp.2021.102131
- Carayannis, E., & Wang, V. (2011). Competitiveness Model—A Double Diamond. *Journal of The Knowledge Economy*, 3(3), 280-293. https://doi.org/10.1007/s13132-011-0038-7
- Carayannis, E., Barth, T., & Campbell, D. (2012). The Quintuple Helix innovation model: global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, 1(1), 1-12. https://doi.org/10.1186/2192-5372-1-2
- Carayannis, E., & Campbell, D. (2014a). Developed democracies versus emerging autocracies: arts, democracy, and innovation in Quadruple Helix innovation systems. *Journal of Innovation and Entrepreneurship,* 3(1). https://doi.org/10.1186/s13731-014-0012-2
- Carayannis, E., & Rakhmatullin, R. (2014b). The Quadruple/Quintuple Innovation Helixes and Smart Specialisation Strategies for Sustainable and Inclusive Growth in Europe and Beyond. *Journal of The Knowledge Economy*, 5(2), 212-239. https://doi.org/10.1007/s13132-014-0185-8

- Carayannis, E., Acikdilli, G., & Ziemnowicz, C. (2019). Creative Destruction in International Trade: Insights from the Quadruple and Quintuple Innovation Helix Models. *Journal of The Knowledge Economy*, 11(4), 1489-1508. https://doi.org/10.1007/s13132-019-00599-z
- Carayannis, E., & Campbell, D. (2021a). Democracy of Climate and Climate for Democracy: The Evolution of Quadruple and Quintuple Helix Innovation Systems. *Journal of The Knowledge Economy*, 12(4), 2050-2082. https://doi.org/10.1007/s13132-021-00778-x
- Carayannis, E., Campbell, D., & Grigoroudis, E. (2021b). Helix Trilogy: The Triple, Quadruple, and Quintuple Innovation Helices from a Theory, Policy, and Practice Set of Perspectives. *Journal of The Knowledge Economy*. https://doi.org/10.1007/s13132-021-00813-x
- Castaneda-Navarrete, J., Leal-Ayala, D., & López-Gómez, C. (2020). (rep.). *Comparing the UK's Response to Industry 4.0: An International Perspective* (pp. 1–10). Cambridge, UK: University of Cambridge.
- Castelo-Branco, I., Cruz-Jesus, F., & Oliveira, T. (2019). Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, 107, 22-32. https://doi.org/10.1016/j.compind.2019.01.007
- Chan, L. & Wu, M. (2002). Quality function deployment: A literature review. European Journal of Operational Research, 143(3), 463-497. https://doi.org/10.1016/S0377-2217(02)00178-9
- Chen, Y. (2020). A Survey on Industrial Information Integration 2016–2019. *Journal Of Industrial Integration And Management*, 05(01), 33-163. https://doi.org/10.1142/s2424862219500167
- Chikwendu, O., Chima, A., & Edith, M. (2020). The optimization of overall equipment effectiveness factors in a pharmaceutical company. *Heliyon*, 6(4), e03796. https://doi.org/10.1016/j.heliyon.2020.e03796
- Chinoracky, R., Kurotova, J., & Janoskova, P. (2021). Measuring the impact of digital technologies on transport industry – macroeconomic perspective. *Transportation Research Procedia*, 55, 434-441. https://doi.org/10.1016/j.trpro.2021.07.092
- Choudhary, V., & Mishra, A. (2021). Analyzing the Critical Success Enablers of Industry 4.0 Using Hybrid Fuzzy AHP–CoCoSo Method. *Journal Of Industrial*

*Integration And Management*, 6(2), 1-22. https://doi.org/10.1142/s2424862221500184

- Cohen, Y., Faccio, M., Pilati, F., & Yao, X. (2019). Design and management of Digital Manufacturing and assembly systems in the Industry 4.0 Era. *The International Journal of Advanced Manufacturing Technology*, 105(9), 3565–3577. https://doi.org/10.1007/s00170-019-04595-0
- Collis, D. J. & Montgomery, C.A. (1995) Competing on Resources: Strategy in the 1990s. *Harvard Business Review*, 73 (4), 118–128.
- Csapi, V., & Balogh, V. (2020). A financial performance-based assessment of smes' competitiveness – an analysis of Hungarian and US small businesses. Problems and Perspectives in Management, 18(3), 452–464. https://doi.org/10.21511/ppm.18(3).2020.37
- Culot, G., Nassimbeni, G., Orzes, G. & Sartor, M., (2020). Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*, 226, p.107617.https://doi.org/10.1016/j.ijpe.2020.107617
- D'Aveni, R. A. (2018). The 3-D Printing Playbook. *Harvard Business Review*, (July-August), pp.106-113.
- Dalenogare, L., Benitez, G., Ayala, N., & Frank, A. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal Of Production Economics*, 204, 383-394. https://doi.org/10.1016/j.ijpe.2018.08.019
- Dhewanto, W., Herliana, S., Yunita, F., Nur Rizqi, V., & Williamson, I. (2020). Quadruple Helix Approach to Achieve International Product Quality for Indonesian Food SMEs. *Journal of The Knowledge Economy*. https://doi.org/10.1007/s13132-020-00644-2
- Duan, L., & Da Xu, L. (2021). Data Analytics in Industry 4.0: A Survey. *Information Systems Frontiers*. https://doi.org/10.1007/s10796-021-10190-0
- Ejaz, M. R. (2022). Implementation of Industry 4.0 Enabling Technologies from Smart Manufacturing Perspective. *Journal of Industrial Integration and Management*. https://doi.org/10.1142/s242486222250021x
- Evans, G. (2019). Emergence of a digital cluster in east London: birth of a new hybrid firm. *Competitiveness Review: An International Business Journal*, 29(3), 253-266. https://doi.org/10.1108/cr-08-2018-0047

- Farinha, L., Ferreira, J., & Gouveia, B. (2014). Networks of Innovation and Competitiveness: A Triple Helix Case Study. *Journal of The Knowledge Economy*, 7(1), 259-275. https://doi.org/10.1007/s13132-014-0218-3
- Ferreira, W., Armellini, F. & Eulalia, L. (2020). Simulation in industry 4.0: A state-of-the-art review. *Computers & Industrial Engineering*, 149, p.106868.https://doi.org/10.1016/j.cie.2020.106868
- Firk, S., Hanelt, A., Oehmichen, J., & Wolff, M. (2021). Chief digital officers: An analysis of the presence of a centralized digital transformation role. *Journal of Management Studies*, 58(7), 1800–1831. https://doi.org/10.1111/joms.12718
- Frank, A., Dalenogare, L., & Ayala, N. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal Of Production Economics*, 210, 15-26. https://doi.org/10.1016/j.ijpe.2019.01.004
- Fritzsche, R., Voigt, E., Schaffrath, R., Todtermuschke, M. & Rober, M. (2020). Automated design of product-flexible car body fixtures with software supported part alignment using particle swarm optimization. Procedia CIRP, 88, 157-162. https://doi.org/10.1016/j.procir.2020.05.028
- Fu, Q., Wang, Q., Xu, X., & Lian, Z. (2017). A two-product newsvendor system with a flexible product. International Journal of Production Economics, 193, 590-601. https://doi.org/10.1016/j.ijpe.2017.08.018
- Genest, M. & Gamache, S. (2020). Prerequisites for the Implementation of Industry 4.0 in Manufacturing SMEs. *Procedia Manufacturing*, 51, pp.1215-1220.https://doi.org/10.1016/j.promfg.2020.10.170
- Genzorova, T., Corejova, T., & Stalmasekova, N. (2019). How digital transformation can influence business model, Case study for transport industry. *Transportation Research Procedia*, 40, 1053-1058. https://doi.org/10.1016/j.trpro.2019.07.147
- Gibbons, P. M., & Burgess, S. C. (2010). Introducing Oee as a measure of Lean Six Sigma Capability. *International Journal of Lean Six Sigma*, 1(2), 134–156. https://doi.org/10.1108/20401461011049511
- Gorkhali, A. (2022). Industry 4.0 and Enabling Technologies: Integration Framework and Challenges. *Journal Of Industrial Integration And Management*, 7(1), 1-38. https://doi.org/10.1142/s2424862222500075

- Gorkhali, A., & Chowdhury, R. (2022). Blockchain and the Evolving Financial Market: A Literature Review. *Journal Of Industrial Integration And Management*, 07(01), 47-81. https://doi.org/10.1142/s242486222150024x
- Gruber, F.E. (2013). Industry 4.0: A Best Practice Project of the Automotive Industry. In: Kovács, G.L., Kochan, D. (eds) Digital Product and Process Development Systems. NEW PROLAMAT 2013. IFIP Advances in Information and Communication Technology, vol 411. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-41329-2_5
- Grundel, I., & Dahlström, M. (2016). A Quadruple and Quintuple Helix Approach to Regional Innovation Systems in the Transformation to a Forestry-Based Bioeconomy. *Journal of The Knowledge Economy*, 7(4), 963-983. https://doi.org/10.1007/s13132-016-0411-7
- Guerra, A. L., Gidel, T., & Vezzetti, E. (2016). Toward a common procedure using likert and likert-type scales in small groups comparative design observations. In *DS 84: Proceedings of the DESIGN 2016 14th International Design Conference* (pp. 23-32).
- Haipeter, T. (2020). Digitalisation, unions and participation: The German case of 'industry 4.0.' *Industrial Relations Journal*, 51(3), 242–260. https://doi.org/10.1111/irj.12291
- Harris, J. E., Boushey, C., Bruemmer, B., & Archer, S. L. (2008). Publishing Nutrition Research: A review of nonparametric methods, part 3. Journal of the American Dietetic Association, 108(9), 1488–1496. https://doi.org/10.1016/j.jada.2008.06.426
- Hayes, R.H. & Pisano, G. P. (1994). Beyond World-Class: The New Manufacturing Strategy. *Harvard Business Review*. 72 (1), 77–84.
- Hedman, R., Subramaniyan, M., & Almström, P. (2016). Analysis of critical factors for automatic measurement of OEE. *Procedia CIRP*, 57, 128–133. https://doi.org/10.1016/j.procir.2016.11.023
- Herpen, E., & de Hooge, I. (2019). When product attitudes go to waste: Wasting products with remaining utility decreases consumers' product attitudes. Journal Of Cleaner Production, 210, 410-418. https://doi.org/10.1016/j.jclepro.2018.10.331

- Hizam-Hanafiah, M., Soomro, M., & Abdullah, N. (2020). Industry 4.0 Readiness Models: A Systematic Literature Review of Model Dimensions. *Information*, 11(7), 364. https://doi.org/10.3390/info11070364
- Horvat, D., Moll, C., & Weidner, N. (2019). Why and How to Implement Strategic Competence Management in Manufacturing SMEs?. *Procedia Manufacturing*, 39, 824-832. https://doi.org/10.1016/j.promfg.2020.01.422
- Hsu, Y.-C., Pearn, W. L., & Chuang, Y.-F. (2009). Sample size determination for production yield estimation with multiple independent process characteristics. European Journal of Operational Research, 196(3), 968–978. https://doi.org/10.1016/j.ejor.2008.04.029
- Huggins, R., Prokop, D., & Thompson, P. (2021). (rep.). *UK Competitiveness Index 2021*. Cardiff University & Nottingham Trent University.
- Hung, Y., Li, L., & Cheng, T. (2022). Uncovering hidden capacity in overall equipment effectiveness management. *International Journal of Production Economics*, 248, 108494. https://doi.org/10.1016/j.ijpe.2022.108494
- Iannone, R., & Elena, M. (2013). Managing Oee to optimize factory performance. *Operations Management*. https://doi.org/10.5772/55322
- Ivanova, I. (2014). Quadruple Helix Systems and Symmetry: A Step Towards Helix Innovation System Classification. *Journal of The Knowledge Economy*, 5(2), 357-369. https://doi.org/10.1007/s13132-014-0201-z
- Jantunen, E., Campos, J., Sharma, P., & Baglee, D. (2017). Digitalisation of maintenance. *2017 2nd International Conference on System Reliability and Safety (ICSRS)*. https://doi.org/10.1109/icsrs.2017.8272846
- Javaid, M., Haleem, A., Singh, R., & Suman, R. (2021). Significant Applications of Big Data in Industry 4.0. *Journal Of Industrial Integration And Management*, 06(04), 429-447. https://doi.org/10.1142/s2424862221500135
- Jiang, H., Kwong, C., Okudan Kremer, G. & Park, W. (2019). Dynamic modelling of customer preferences for product design using DENFIS and opinion mining. Advanced Engineering Informatics, 42, 100969. https://doi.org/10.1016/j.aei.2019.100969
- Joshi, A., Kale, S., Chandel, S., & Pal, D. (2015). Likert scale: Explored and explained. *British Journal of Applied Science & Technology*, *7*(4), 396–403. https://doi.org/10.9734/bjast/2015/14975

- Kambanou, M. L., & Sakao, T. (2020). 'Using life cycle costing (LCC) to select circular measures: A discussion and practical approach.' *Resources, Conservation and Recycling*, 155, 104650.
- Kang, H., Lee, J., Choi, S., Kim, H., Park, J., & Son, J. et al. (2016). Smart manufacturing: Past research, present findings, and future directions. *International Journal of Precision Engineering and Manufacturing-Green Technology*, 3(1), 111-128. https://doi.org/10.1007/s40684-016-0015-5
- Kaplan, R. S. & Norton, D.P. (2008). Mastering the Management System. Special Issue on HBS Centennial. *Harvard Business Review*, 86, (1), 62–77.
- Karnik, N., Bora, U., Bhadri, K., Kadambi, P., & Dhatrak, P. (2022). A comprehensive study on current and future trends towards the characteristics and enablers of industry 4.0. *Journal of Industrial Information Integration*, 27, 100294. https://doi.org/10.1016/j.jii.2021.100294
- Kettunen, J., Grushka-Cockayne, Y., Degraeve, Z. & De Reyck, B. (2015). New product development flexibility in a competitive environment. European Journal of Operational Research, 244(3), 892-904. https://doi.org/10.1016/j.ejor.2015.02.016
- Khan, I., & Javaid, M. (2021). Role of Internet of Things (IoT) in Adoption of Industry 4.0. *Journal Of Industrial Integration And Management*, 2150006. https://doi.org/10.1142/s2424862221500068
- Kim, J. (2017). A Review of Cyber-Physical System Research Relevant to the Emerging IT Trends: Industry 4.0, IoT, Big Data, and Cloud Computing. *Journal Of Industrial Integration And Management*, 02(03), 1750011. https://doi.org/10.1142/s2424862217500117
- King, G., Rameshwar, J., & Syan, C. (2020). Industry 4.0 in a Small Commodity-Based Economy: A Vehicle for Stimulating Innovation. *Journal Of Industrial Integration And Management*, 05(03), 365-391. https://doi.org/10.1142/s242486222050013x
- Kolehmainen, J., Irvine, J., Stewart, L., Karacsonyi, Z., Szabó, T., Alarinta, J., & Norberg, A. (2015). Quadruple Helix, Innovation and the Knowledge-Based Development: Lessons from Remote, Rural and Less-Favoured Regions. *Journal of The Knowledge Economy*, 7(1), 23-42. https://doi.org/10.1007/s13132-015-0289-9
- Kopp, R., Hirsch Kreinsen, H., Preenen, P., Dhondt, S., & Kohlgrüber, M. (2019). Sociotechnical Perspectives on Digitalisation and industry 4.0. International

*Journal of Technology Transfer and Commercialisation*, 16(3), 290. https://doi.org/10.1504/ijttc.2019.10021352

- Kothari, R.C. (2004): Research Methodology, Methods and techniques New Age, International (P) Ltd, Publisher Ansari Road, Daryaganj, New Delhi. pp. 78-269, pp. 344-351.
- Krajewski, L., Ritzman, L. and Malhotra, M. (2013). Operations Management. 10th ed. Boston: Pearson, 114-116.
- Kumar, R. (2014): Research Methodology, a step-by-step guide for beginners, Fourth Edition, SAGE.
- Kumar, R., Singh, R. & Dwivedi, Y. (2020). Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: Analysis of challenges. *Journal of Cleaner Production*, 275, p.124063. https://doi.org/10.1016/j.jclepro.2020.124063
- Kumar, G., Bakshi, A., Khandelwal, A., Panchal, A., & Soni, U. (2021). Analyzing Industry 4.0 Implementation Barriers in Indian SMEs. *Journal Of Industrial Integration And Management*, 07(01), 153-169. https://doi.org/10.1142/s2424862221500020
- Kumar, S., Suhaib, M., Asjad, M., & Salah, B. (2022). Industry 4.0 and Its Suitability in Post COVID-19. *Journal Of Industrial Integration And Management*, 7(1), 1-20. https://doi.org/10.1142/s2424862222500129
- Kusiak, A. (2017). Smart manufacturing. *International Journal of Production Research*, 56(1-2), 508-517. https://doi.org/10.1080/00207543.2017.1351644
- Łabędzka, J. (2021). Industry 4.0 — policy-based approaches to efficient implementation in SMEs. *Engineering Management In Production And Services*, 13(4), 72-78. https://doi.org/10.2478/emj-2021-0032
- Lafou, M., Mathieu, L., Pois, S. & Alochet, M. (2016). Manufacturing System Flexibility: Product Flexibility Assessment. Procedia CIRP, 41, 99-104. https://doi.org/10.1016/j.procir.2015.12.046
- Lafuente, E., Szerb, L., & Rideg, A. (2020). A system dynamics approach for assessing smes' competitiveness. Journal of Small Business and Enterprise Development, 27(4), 555–578. https://doi.org/10.1108/jsbed-06-2019-0204
- Lakho, T. H., Khan, M. A., Virk, S. I., & Indher, A. A. (2020). *In Proceedings of the 2nd African International Conference on Industrial Engineering and Operations Management* (pp. 3087–3097). Harare, Zimbabwe; IEOM Society International.

- Lall, S. (2004). Reinventing Industrial Strategy: The Role of Government Policy in Building Industrial Competitiveness, *G-24 Discussion Papers 28, United Nations Conference on Trade and Development*
- Lanke, A. A., Hoseinie, S. H., & Ghodrati, B. (2016). Mine production index (mpi)-extension of OEE for bottleneck detection in mining. *International Journal of Mining Science and Technology*, 26(5), 753–760. https://doi.org/10.1016/j.ijmst.2016.05.050
- Lasi, H., Fettke, P., Kemper, H., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business &Amp; Information Systems Engineering*, 6(4), 239-242. https://doi.org/10.1007/s12599-014-0334-4
- Leary, A. (2021). Biden Orders Broad Supply-Chain Review Amid Chip Shortages. [online] WSJ. Available at: <https://www.wsj.com/articles/biden-to-address-chip-shortages-supply-chain-problems-with-executive-action-11614160803> [Accessed 28 February 2021].
- Leydesdorff, L. (2011). The Triple Helix, Quadruple Helix, …, and an N-Tuple of Helices: Explanatory Models for Analyzing the Knowledge-Based Economy?. *Journal of The Knowledge Economy*, *3*(1), 25-35.
- Li, D., Y. Huang, H. Sun, & Zhi, B. (2022). 'Achieving sustainability in sharing-based product service system: A contingency perspective.' *Journal of Cleaner Production,* 332, 129997.
- Li, H., & Yang, C. (2021). Digital Transformation of Manufacturing Enterprises. *Procedia Computer Science*, 187, 24-29. https://doi.org/10.1016/j.procs.2021.04.029
- Li, L. (2018). China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0". Technological Forecasting & Social Change, 135, 66-74. https://doi.org/10.1016/j.techfore.2017.05.028
- Li, X., Z. Wang, C, Chen, & Zheng, P. (2021). 'A data-driven reversible framework for achieving Sustainable Smart product-service systems.' Journal of Cleaner Production, 279, 123618.
- Li, Y., Tang, J., Chin, K., Luo, X., Pu, Y. & Jiang, Y. (2012). On integrating multiple type preferences into competitive analyses of customer requirements in product planning. International Journal of Production Economics, 139(1), 168-179. https://doi.org/10.1016/j.ijpe.2012.03.031

- Lis, A. (2019). The significance of proximity in cluster initiatives. *Competitiveness Review: An International Business Journal*, 29(3), 287-310. https://doi.org/10.1108/cr-08-2018-0050
- Liu, J., Tang, W., Chen, G., Lu, Y., Feng, C., & Tu, X. M. (2016). Correlation and agreement: overview and clarification of competing concepts and measures. *Shanghai Archives of Psychiatry*, *28*(2), 115–120. https://doi.org/10.11919/j.issn.1002-0829.216045
- Liu, C., Zheng, P., & Xu, X. (2021). Digitalisation and Servitisation of machine tools in the era of industry 4.0: A Review. *International Journal of Production Research*, 61(12), 4069–4101. https://doi.org/10.1080/00207543.2021.1969462
- López-Gómez, C. (2021). (rep.). *Driving technology diffusion in the UK: Industry 4.0 and the Made Smarter Programme* (pp. 1–8). Cambridge, UK: University of Cambridge.
- Lu, Y. (2017). Cyber Physical System (CPS)-Based Industry 4.0: A Survey. *Journal Of Industrial Integration And Management*, 02(03), 1750014. https://doi.org/10.1142/s2424862217500142
- Lucato, W., Pacchini, A., Facchini, F., & Mummolo, G. (2019). Model to evaluate the Industry 4.0 readiness degree in Industrial Companies. *IFAC-Papersonline,* 52(13), 1808-1813. https://doi.org/10.1016/j.ifacol.2019.11.464
- Majeed, A., Zhang, Y., Ren, S., Lv, J., Peng, T., Waqar, S. & Yin, E. (2021). A big data-driven framework for sustainable and smart additive manufacturing. *Robotics and Computer-Integrated Manufacturing*, 67, p.102026. https://doi.org/10.1016/j.rcim.2020.102026
- Mariani, M. & Borghi, M. (2019). Industry 4.0: A bibliometric review of its managerial intellectual structure and potential evolution in the service industries. *Technological Forecasting and Social Change*, 149, p.119752. https://doi.org/10.1016/j.techfore.2019.119752
- Mastrogiacomo, L., F. Barravecchia, F. Franceschini, & Marimon, F. (2021). 'Mining quality determinants of product-service systems from user-generated contents.' *Quality Engineering*, 33 (3), 425-442.
- Matarazzo, M., Penco, L., Profumo, G., & Quaglia, R. (2021). Digital transformation and customer value creation in Made in Italy SMEs: A dynamic capabilities

perspective. *Journal of Business Research*, 123, 642-656. https://doi.org/10.1016/j.jbusres.2020.10.033

- Mateo, F., & Redchuk, A. (2022). Artificial Intelligence as a Process Optimization driver under industry 4.0 framework and the role of IIoT, a bibliometric analysis. *Journal Of Industrial Integration And Management*. https://doi.org/10.1142/s2424862222500130
- Medojevic, M., Diaz Villar, P., Cosic, I., Rikalovic, A., Sremcev, N. & Lazarevic, M. (2018). Energy Management in Industry 4.0 Ecosystem: a Review on Possibilities and Concerns. *Proceedings of the 29th International DAAAM Symposium 2018*, pp.0674-0680. https://doi.org/10.2507/29th.daaam.proceedings.097
- Miragliotta, G., Sianesi, A., Convertini, E., & Distante, R. (2018). Data Driven Management in industry 4.0: A method to measure data productivity. *IFAC-PapersOnLine*, 51(11), 19–24. https://doi.org/10.1016/j.ifacol.2018.08.228
- Mittal, S., Khan, M., Romero, D., & Wuest, T. (2017). Smart manufacturing: Characteristics, technologies and enabling factors. *Proceedings of the Institution Of Mechanical Engineers, Part B: Journal Of Engineering Manufacture*, 233(5), 1342-1361. https://doi.org/10.1177/0954405417736547
- Mohapatra, B., Tripathy, S., Singhal, D., & Saha, R. (2021). Significance of digital technology in manufacturing sectors: Examination of key factors during Covid-19. *Research in Transportation Economics*, 101134. https://doi.org/10.1016/j.retrec.2021.101134
- Molina-Barrientos, M., Verduzco, T., & Villarreal, B. (2021). OEE APPROACH IN INCREASING PLANT PRODUCTIVITY. *International Journal of Organizational Business Excellence*, 4(1), 21–28.
- Momeni, F., Arab Mazar Yazdi, A., & Najafi, S. (2019). Changing economic systems and institutional dimensions of the Triple Helix model. *Journal of Innovation and Entrepreneurship*, 8(1). https://doi.org/10.1186/s13731-018-0096-1
- Momete, D. (2020). ‘A unified framework for assessing the readiness of European Union economies to migrate to a circular modelling.’ *Science of the Total Environment*, 718, 137375.
- Moreno-Gómez, J., & Lafuente, E. (2019). Analysis of competitiveness in Colombian family businesses. *Competitiveness Review: An International Business Journal*, 30(3), 339-354. https://doi.org/10.1108/cr-11-2018-0074

- Moussa, P., & Hartman, R. (2023). Improvement of Operational Efficiency by Optimising the OEE Score. : A Case Study of a Large Manufacturer. (Dissertation). Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:hj:diva-61915
- Murray, J. (2013). Likert Data: What to Use, Parametric or Non-Parametric? *International Journal of Business and Social Science, 4*(11), 258–264.
- Ng Corrales, L. del, Lambán, M. P., Hernandez Korner, M. E., & Royo, J. (2020). Overall Equipment Effectiveness: Systematic literature review and overview of different approaches. *Applied Sciences*, 10(18), 6469. https://doi.org/10.3390/app10186469
- Nes, N. V. & Cramer, J. (2005). Influencing product lifetime through product design. Business Strategy and the Environment, 14(5), 286-299. https://doi.org/10.1002/bse.491
- Ocampo, J., Hernández-Matías, J., & Vizán, A. (2017). A method for estimating the influence of advanced manufacturing tools on the manufacturing competitiveness of Maquiladoras in the apparel industry in Central America. *Computers in Industry*, 87, 31-51. https://doi.org/10.1016/j.compind.2017.02.001
- Oliveira, S. (2017). High Radicality of Product Innovation and High Flexibility and High Agility of System of Manufacturing: Towards the Smart Factories. Procedia Manufacturing, 11, 1324-1334. https://doi.org/10.1016/j.promfg.2017.07.261
- Ooi, K., Lee, V., Tan, G., Hew, T. & Hew, J., (2018). Cloud computing in manufacturing: The next industrial revolution in Malaysia?. *Expert Systems with Applications*, 93, pp.376-394.https://doi.org/10.1016/j.eswa.2017.10.009
- Oral, M., Cinar, U., & Chabchoub, H. (1999). Linking industrial competitiveness and productivity at the firm level. *European Journal of Operational Research*, 118(2), 271-277. https://doi.org/10.1016/s0377-2217(99)00025-9
- Pacchini, A., Lucato, W., Facchini, F. & Mummolo, G. (2019). The degree of readiness for the implementation of Industry 4.0. *Computers in Industry*, 113, p.103125. https://doi.org/10.1016/j.compind.2019.103125
- Page, C. & Herr, P. (2002). An Investigation of the Processes by Which Product Design and Brand Strength Interact to Determine Initial Affect and Quality Judgments. *Journal of Consumer Psychology*, 12(2), 133-147. https://doi.org/10.1207/153276602760078668

- Palominos, P., Quezada, L., Donoso, J. & Gonzalez, M. (2019). A Model of Economic Evaluation for the Acquisition of Flexible Manufacturing Technologies. *Procedia Manufacturing*, 39, 565-573. https://doi.org/10.1016/j.promfg.2020.01.420
- Parthasarthy, R., & Yin, J. (1996). Computer-integrated manufacturing and competitive performance Moderating effects of organization-wide integration. *Journal of Engineering and Technology Management*, 13(1), 83-110. https://doi.org/10.1016/0923-4748(96)00006-9
- Pisano, G.P. & Willy, C.S. (2009). Restoring American Competitiveness. *Harvard Business Review*, 87 (7-8), 114-125
- Pisano, G. P, & Willy, C.S. (2012). Does America Really Need Manufacturing? *Harvard Business Review*, 94 (3), 94-102.
- Pisano, G. (2015). You Need an Innovation Strategy. *Harvard Business Review*, *93*(6), 44-54.
- Planing, P. (2017). On the origin of innovations—the opportunity vacuum as a conceptual model for the explanation of innovation. *Journal of Innovation and Entrepreneurship*, 6(1). https://doi.org/10.1186/s13731-017-0063-2
- Porter, M. E. & Rivkin, J. W. (2012). The Looming Challenge to U.S Competitiveness. *Harvard Business Review*, 90 (3), 54–61.
- Porter, M. E. & Heppelmann, J. E. (2015). How Smart, Connected Products Are Transforming Companies. *Harvard Business Review*. 93 (10), 97–114.
- Porter, M. E. & Heppelmann, J. E. (2017). Why Every Organization Needs an Augmented Reality Strategy. *Harvard Business Review*, 95 (6), pp46-57
- Rauch, E., Dallasega, P. & Unterhofer, M. (2019). Requirements and Barriers for Introducing Smart Manufacturing in Small and Medium-Sized Enterprises. *IEEE Engineering Management Review*, 47(3), pp.87-94. https://doi.org/10.1109/emr.2019.2931564
- Reyes, G., & Useche, A. (2019). Competitiveness, economic growth and human development in Latin American and Caribbean countries 2006-2015. *Competitiveness Review: An International Business Journal*, 29(2), 139-159. https://doi.org/10.1108/cr-11-2017-0085
- Rojko, A. (2017). Industry 4.0 Concept: Background and Overview. *International Journal of Interactive Mobile Technologies*, 11(5), pp.77-90. https://doi.org/10.3991/ijim.v11i5.7072

- Rousseau, M., Medini, K., Romero, D. & Wuest, T. (2021). Configurators as a means to Leverage Customer-Centric Sustainable Systems - Evidence from the 3D-Printing Domain. *Procedia CIRP*, 96, 103-108. https://doi.org/10.1016/j.procir.2021.01.060
- Saarikko, T., Westergren, U., & Blomquist, T. (2020). Digital transformation: Five recommendations for the digitally conscious firm. *Business Horizons*, 63(6), 825-839. https://doi.org/10.1016/j.bushor.2020.07.005
- Sáenz, M., Knoppen, D. & Tachizawa, E. (2018). Building manufacturing flexibility with strategic suppliers and contingent effect of product dynamism on customer satisfaction. *Journal of Purchasing and Supply Management*, 24, 238-246. https://doi.org/10.1016/j.pursup.2017.07.002
- Sadun, R., Bloom, N. & Reenen, J. V. (2017). Why Do We Undervalue Competent Management? Neither Great Leadership nor Brilliant Strategy Matters Without Operational Excellence. *Harvard Business Review*, 95(5), 120-127.
- Sakao, T., Song, W., & Matschewsky, J. (2017). Creating service modules for customising product/service systems by extending DSM. *CIRP Annals*, 66(1), 21-24. https://doi.org/10.1016/j.cirp.2017.04.107
- Sandengen, O. C., Estensen, L. A., Rødseth, H., & Schjølberg, P. (2016). *In International Workshop of Advanced Manufacturing and Automation* (pp. 14–28). Atlantis Press.
- Savić, D. (2019). From Digitization, Through Digitalization, to Digital Transformation. *Online Searcher*, 43(1), 36-39.
- Schmidbauer, C., Komenda, T. & Schlund, S. (2020). Teaching Cobots in Learning Factories – User and Usability-Driven Implications. *Procedia Manufacturing*, 45, pp.398-404.https://doi.org/10.1016/j.promfg.2020.04.043
- Schmitt, B. (2019). Inside Toyota's Takaoka #2 Line: The Most Flexible Line in The World. [online] *The Drive*. Available at: https://www.thedrive.com/tech/26955/inside-toyotas-takaoka-2-line-the-most-flexible-line-in-the-world [Accessed 21 Dec. 2019].
- Schneider, D., Fröhlich, T., Huth, T. & Vietor, T. (2020). Design for Flexibility – Evaluation Interactions between Product Properties and Production Processes. Procedia CIRP, 91, 814-818. https://doi.org/10.1016/j.procir.2020.02.240
- Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation Coefficients: Appropriate Use and Interpretation. *Anesthesia & Analgesia*, *126*(5), 1763–1768. https://doi.org/10.1213/ane.0000000000002864

- Shao, X., Liu, W., Li, Y., Chaudhry, H. & Yue, X. (2021). Multistage implementation framework for smart supply chain management under industry 4.0. *Technological Forecasting and Social Change*, 162, p.120354.https://doi.org/10.1016/j.techfore.2020.120354
- Sharma, G. (2017). Pros and cons of different sampling techniques. *International Journal of Applied Research*, 3(7), 749–752.
- Singh, A., Klarner, P., & Hess, T. (2020). How do chief digital officers pursue digital transformation activities? The role of organization design parameters. *Long Range Planning*, *53*(3), 101890. https://doi.org/10.1016/j.lrp.2019.07.001
- Sigov, A., Ratkin, L., Ivanov, L., & Xu, L. (2022). Emerging Enabling Technologies for Industry 4.0 and Beyond. *Information Systems Frontiers*, https://doi.org/10.1007/s10796-021-10213-w
- Sminia, H., Ates, A., Paton, S., & Smith, M. (2019). High value manufacturing: Capability, appropriation, and governance. *European Management Journal*, 37(4), 516-528. https://doi.org/10.1016/j.emj.2018.11.004
- Sony, M. (2020). Pros and cons of implementing industry 4.0 for the organizations: A review and synthesis of evidence. *Production & Manufacturing Research*, *8*(1), 244–272. https://doi.org/10.1080/21693277.2020.1781705
- Sony, M., & Aithal, P. S. (2020). Developing an industry 4.0 readiness model for Indian engineering industries. *International Journal of Management, Technology, and Social Sciences (IJMTS)*, *5*(2), 141-153.
- Sony, M., & Naik, S. (2019). Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. *Benchmarking: An International Journal*, 27(7), 2213-2232. https://doi.org/10.1108/bij-09-2018-0284
- Spence, C. & Gallace, A. (2011). Multisensory design: Reaching out to touch the consumer. Psychology and Marketing, 28(3), 267-308. https://doi.org/10.1002/mar.20392
- Srinivasan, R., Giannikas, V., McFarlane, D., & Thorne, A. (2018). Customising with 3D printing: The role of intelligent control. Computers In Industry, 103, 38-46. DOI: 10.1016/j.compind.2018.09.003
- Stalk G., Evans, P. & Shulman, L. E. (1992). Competing on Capabilities: The New Rules of Corporate Strategy. *Harvard Business Review*, (March-April), 57-69

- Suh, E., de Weck, O., & Chang, D. (2007). Flexible product platforms: framework and case study. Research In Engineering Design, 18(2), 67-89. https://doi.org/10.1007/s00163-007-0032-z
- Sullivan, G. M., & Artino, A. R. (2013). Analyzing and interpreting data from likert-type scales. *Journal of Graduate Medical Education*, *5*(4), 541–542. https://doi.org/10.4300/jgme-5-4-18
- Sum, N., & Jessop, B. (2012). Competitiveness, the Knowledge-Based Economy and Higher Education. *Journal of The Knowledge Economy*, 4(1), 24-44. https://doi.org/10.1007/s13132-012-0121-8
- Tahir, N., & Tahir, P. (2019). Does competition explain growth in OECD and BRICS countries?. *Competitiveness Review: An International Business Journal*, 29(5), 515-533. https://doi.org/10.1108/cr-10-2018-0063
- Tripsas, M. (2008). Customer preference discontinuities: a trigger for radical technological change. Managerial and Decision Economics, 29(2-3), 79-97. https://doi.org/10.1002/mde.1389
- Venkatakrishnaiah, L., & Ramanathan, K. (2019). The Evolving role of Chief Digital Officer. *International Journal of Advance Research in Computer Science and Management Studies*, *7*(7), 1-12.
- Verhoef, P., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, 122, 889-901. https://doi.org/10.1016/j.jbusres.2019.09.022
- Veryzer, R. (1999). A nonconscious processing explanation of consumer response to product design. Psychology and Marketing, 16(6), 497-522. https://doi.org/10.1002/(SICI)1520-6793(199909)16:6<497: AID-MAR4>3.0.CO;2-Z
- Vinokurova, N. (2019). Reshaping demand landscapes: How firms change customer preferences to better fit their products. Strategic Management Journal, 40(13), 2107-2137. https://doi.org/10.1002/smj.3074
- Weller, C., Kleer, R. & Piller, F. (2015). Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited. *International Journal of Production Economics*, 164, pp.43-56. https://doi.org/10.1016/j.ijpe.2015.02.020

- Wang, Z., Pang, C. & Ng, T. (2019). Robust scheduling optimization for flexible manufacturing systems with replenishment under uncertain machine failure disruptions. Control Engineering Practice, 92, 104094. https://doi.org/10.1016/j.conengprac.2019.07.012
- Wei, W., Ji, J., Wuest, T. & Tao, F. (2017). Product Family Flexible Design Method based on Dynamic Requirements Uncertainty Analysis. Procedia CIRP, (60), 332-337. https://doi.org/10.1016/j.procir.2017.01.037
- Wells, L., Camelio, J., Williams, C. & White, J. (2014). Cyber-physical security challenges in manufacturing systems. *Manufacturing Letters*, 2(2), pp.74-77. https://doi.org/10.1016/j.mfglet.2014.01.005
- Wenderoth, M. (2013). Four-Phase-Model for the Implementation of Shared Services (Ph.D.). University of Pécs.
- Xu, L. (2020). The contribution of systems science to Industry 4.0. *Systems Research and Behavioral Science*, 37(4), 618-631. https://doi.org/10.1002/sres.2705
- Yazdi, P. G., Azizi, A., & Hashemipour, M. (2018). An empirical investigation of the relationship between overall equipment efficiency (OEE) and manufacturing sustainability in Industry 4.0 with Time Study Approach. *Sustainability*, 10(9), 3031. https://doi.org/10.3390/su10093031
- Yüksel, H. (2020). An empirical evaluation of industry 4.0 applications of companies in Turkey: The case of a developing country. *Technology in Society*, 63, p.101364.https://doi.org/10.1016/j.techsoc.2020.101364
- Zahidi, S. (2020). This is how countries can rebuild competitive economies for people and planet. [online] *World Economic Forum*. Available at: <https://www.weforum.org/agenda/2020/12/how-countries-can-rebuild-competitive-economies-for-people-and-planet/> [Accessed 27 February 2021].
- Zahra, S., & Das, S. (1993). Building competitive advantage on manufacturing resources. *Long Range Planning*, 26(2), 90-100. https://doi.org/10.1016/0024-6301(93)90140-b
- Zarreh, A., Wan, H., Lee, Y., Saygin, C. & Janahi, R. (2019). Risk Assessment for Cyber Security of Manufacturing Systems: A Game Theory Approach. *Procedia Manufacturing*, 38, pp.605-612.https://doi.org/10.1016/j.promfg.2020.01.077
- Zhang, C., & Chen, Y. (2020). A Review of Research Relevant to the Emerging Industry Trends: Industry 4.0, IoT, Blockchain, and Business Analytics. *Journal Of*

*Industrial Integration And Management*, 05(01), 165-180. https://doi.org/10.1142/s2424862219500192

- Zhang, Q., Vonderembse, M. and Cao, M. (2009). Product concept and prototype flexibility in manufacturing: Implications for customer satisfaction. European Journal of Operational Research, 194(1), 143-154. DOI: 10.1016/j.ejor.2007.12.013
- Zheng, P., wang, H., Sang, Z., Zhong, R., Liu, Y., & Liu, C. et al. (2018). Smart manufacturing systems for Industry 4.0: Conceptual framework, scenarios, and future perspectives. *Frontiers of Mechanical Engineering*, 13(2), 137-150. https://doi.org/10.1007/s11465-018-0499-5
- Zikmund, W.G., Babin, B.J., Carr, J.C., Griffin, M. (2009): Business Research Methods, 8th Edition, Cengage Learning EMEA

# 8 Appendixes

## 8.1 Cover Letter

Dear Sir/Madam,

My name is Muhammad Rahim Ejaz and I am a PhD student in the Faculty of Business & Economics, University of Pecs, Hungary. The ideal respondents of this survey are production/operation managers/assistants.

Your participation is voluntary and confidential. Your cooperation is highly important. The aim of this study is to explore the impact of the implementation of Industry 4.0 technologies in manufacturing organizations. The study is aimed to conduct research on the manufacturing organizations working in the UK.

Through your participation in this questionnaire, you are granting your help and contributing to the research in the field of production and operations management. The link is given below.

https://forms.office.com/r/WkqD4kjwK2

It will only take a few minutes of your precious time. I will be obliged for this kind favor.

In case of any questions, you can reach out to me at rahim.ejaz@live.com. Thank you.

Regards,

Muhammad Rahim Ejaz

PhD Candidate

Faculty of Business & Economics

University of Pecs, Hungary

## 8.2 A Gentle Reminder

Dear Sir/Madam,

My name is Muhammad Rahim Ejaz and I am a PhD student in the Faculty of Business & Economics, University of Pecs, Hungary. The ideal respondents of this survey are production/operation managers/assistants.

I contacted you a couple of weeks ago. Your participation is voluntary and confidential. Your cooperation is highly important. The aim of this study is to explore the impact of the implementation of Industry 4.0 technologies in manufacturing organizations. The study is aimed to conduct research on the manufacturing organizations working in the UK.

Through your participation in this questionnaire, you are granting your help and contributing to the research in the field of production and operations management. The link is given below.

https://forms.office.com/r/WkqD4kjwK2

It will only take a few minutes of your precious time. I will be obliged for this kind favor.

In case of any questions, you can reach out to me at rahim.ejaz@live.com. Thank you.

Regards,

Muhammad Rahim Ejaz

PhD Candidate

Faculty of Business & Economics

University of Pecs, Hungary

## 8.3 Online Questionnaire

# The impact of Industry 4.0 technologies on the manufacturing industry

My name is Muhammad Rahim Ejaz and I am a PhD student in the Faculty of Business & Economics, University of Pecs, Hungary. The ideal respondents of this survey are production/operation managers/assistants. Your participation is voluntary and confidential. Your cooperation is highly important. The aim of this study is to explore on the impact of the implementation of Industry 4.0 technologies in the manufacturing organizations..The study is aimed to conduct research on the manufacturing organizations working in the UK.

Through your participation in this questionnaire you are granting your help and contributing to the researcch in the field of production and operations management.

It will only take few minutes of your precious time. I will be obliged for this kind favour.

Incase of any questions, you can reach out to me at rahim.ejaz@live.com. Thank you

...

## Demographic Information

1. How many years of experience do you have in your field?

- ◯ Under 5 years
- ◯ 5-10 years
- ◯ 10-15 years
- ◯ 15 + years

2. What is your education level?

- ◯ High School
- ◯ Bachelors
- ◯ Masters
- ◯ PhD
- ◯ Other

3. What is your field of study?

- ◯ Natural Sciences
- ◯ Engineering Sciences
- ◯ Social Studies
- ◯ Other

4. How long have you been working in a mangerial position?

- ◯ Upto 5 years
- ◯ 5-10 years
- ◯ 11-15 years
- ◯ Above 15 years

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## Organization Information

5. How will you classify your organization?

- ◯ Small (1-99 emplyees)
- ◯ Medium (100-499 employees)
- ◯ Large (500 +)

6. Which one of these Industry 4.0 enabled digital technologies your organization use in the manufacturing/operations department?

- [ ] ERP Software
- [ ] Big Data Aanalytcis
- [ ] Cloud Computing
- [ ] 3D Printing
- [ ] Internet of Things
- [ ] Simulation
- [ ] Virtual Reality/Augmented Reality
- [ ] Robots
- [ ] Other

7. If you have anything else to add, your comments and opinions are welcome.

Enter your answer

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## Readiness of Industry 4.0 Technologies Implementation

8. Has your organization started the process of implementation of Industry 4.0 technologies

- ◯ Yes
- ◯ No

9. Is implementation of Industry 4.0 technologies part of your organizational strategy?

- ◯ Yes
- ◯ No

10. If implementation of Industry 4.0 technologies part of your organizational strategy; since when you have implemented it?

- ◯ Less than 1 year
- ◯ 1-3 years
- ◯ 3-5 years
- ◯ More than 5 years

11. What is the completion status of prerequisites of your organization to check its readiness level to implement Industry 4.0 technologies?

| | Not Started | Initial Phase (0-15%) | Primary Phase (15% -50%) | Advanced phase (50%-85%) | Ready (100%) |
|---|---|---|---|---|---|
| Professionally trained workforce | ◯ | ◯ | ◯ | ◯ | ◯ |
| Financial capacity | ◯ | ◯ | ◯ | ◯ | ◯ |
| Technical capabilities | ◯ | ◯ | ◯ | ◯ | ◯ |
| Installed certified hardware | ◯ | ◯ | ◯ | ◯ | ◯ |
| High speed internet networking | ◯ | ◯ | ◯ | ◯ | ◯ |
| Firewall for data security | ◯ | ◯ | ◯ | ◯ | ◯ |
| Awareness of limitations | ◯ | ◯ | ◯ | ◯ | ◯ |
| Knowledge of manufacturing SOPs | ◯ | ◯ | ◯ | ◯ | ◯ |
| Thorough mapping of operational processes | ◯ | ◯ | ◯ | ◯ | ◯ |
| Interactive software for production ordering & scheduling capacity | ◯ | ◯ | ◯ | ◯ | ◯ |
| Integration of systems for interoperability | ◯ | ◯ | ◯ | ◯ | ◯ |

12. If you have anything else to add, your comments and opinions are welcome.

Enter your answer

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## Overall Equipment Effectiveness (OEE)

13. What is your current estimated OEE?

- ◯ Less than 50%
- ◯ 50%-65%
- ◯ 65%-80%
- ◯ Above 80%

14. Was the OEE lower before the implementation of Industry 4.0 technologies?

- ◯ Yes
- ◯ No
- ◯ Other

15. What is your OEE goal?

- ◯ Above 60%
- ◯ Above 70%
- ◯ Above 80%
- ◯ Above 90%

16. In your opnion what is the impact of Industry 4.0 technologies on the overall equipment effectiveness (OEE) in the manufacturing department

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Decreased downtime | ○ | ○ | ○ | ○ | ○ |
| Decreased setup time | ○ | ○ | ○ | ○ | ○ |
| Decreased Defective Products | ○ | ○ | ○ | ○ | ○ |
| Decrease in Performance loss | ○ | ○ | ○ | ○ | ○ |
| Decreased speed losses | ○ | ○ | ○ | ○ | ○ |
| Decreased planned/unplanned stoppages | ○ | ○ | ○ | ○ | ○ |

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## Competitiveness

17. In your opnion what is the impact of Industry 4.0 technologies on the overall operational competitivness of the organization

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Reduction in the use of resources | ○ | ○ | ○ | ○ | ○ |
| Reduction in cost of production | ○ | ○ | ○ | ○ | ○ |
| Increased operational/manufacturing capabilities | ○ | ○ | ○ | ○ | ○ |
| Increased R&D | ○ | ○ | ○ | ○ | ○ |
| Increased Product Quality | ○ | ○ | ○ | ○ | ○ |
| Increased Mass Customization | ○ | ○ | ○ | ○ | ○ |
| Increased Operational Effeciency | ○ | ○ | ○ | ○ | ○ |
| Flexible Mnaufacturing Process | ○ | ○ | ○ | ○ | ○ |
| More Flexible Product Design | ○ | ○ | ○ | ○ | ○ |

18. If you have anything else to add, your comments and opinions are welcome.

Enter your answer

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## Circular Economic Strategies

19. Does your organization implement any of these strategies to minimize the use of raw material/resources and to increase value creation?

- [ ] Recycle
- [ ] Recover
- [ ] Remanufacture
- [ ] Repurpose
- [ ] Refurbish
- [ ] Repair
- [ ] Reuse
- [ ] Reduce
- [ ] None of these

20. If Yes, what is the impact of these startegies on your organization?

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Low Production Cost | ○ | ○ | ○ | ○ | ○ |
| Less Supply Chain Barriers | ○ | ○ | ○ | ○ | ○ |
| Sustainable Products & Parts | ○ | ○ | ○ | ○ | ○ |
| Low Industrial Waste | ○ | ○ | ○ | ○ | ○ |
| Less Raw Material Consumption | ○ | ○ | ○ | ○ | ○ |
| Low Supply Chain Cost | ○ | ○ | ○ | ○ | ○ |
| Higher Demand | ○ | ○ | ○ | ○ | ○ |

21. If you have anything else to add, your comments and opinions are welcome. Thank you

Enter your answer

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Submit

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## 8.4 List of Publications

1. Smart Manufacturing as a Management Strategy to Achieve Sustainable Competitiveness. (Not a Duplication)

Journal of the Knowledge Economy

https://doi.org/10.1007/s13132-023-01097-z

2. Designing a Conceptual Framework for Industry 4.0 Technologies to Enable Circular Economy Ecosystem

Managing Global Transitions: International Research Journal (Accepted and to be published in June 2023)

3. Implementation of Industry 4.0 Enabling Technologies from Smart Manufacturing Perspective Journal of Industrial Integration and Management

https://doi.org/10.1142/S242486222250021X

4. The Future of Flexible Products Manufacturing by Using Industry 4.0 Technologies in Regard with Consumer Preferences.

The Hungarian Journal of Marketing and Management Vol. 55 No. 03 (2021)

https://doi.org/10.15170/MM.2021.55.03.01

5. The Private Label Brands (PLBs): A National Brand Manufacturer-Retailer Relationship Perspective.

VI. International Winter Conference of Economics PhD Students and Researchers, Szent István University Gödöllő, Hungary, 2020

https://oszkdk.oszk.hu/DRJ/32826/cimkes

6. Smart manufacturing as a management strategy to achieve sustainable competitiveness. (Not a Duplication)

Farkas Ferenc II International Scientific Conference 2020

https://digitalia.lib.pte.hu/hu/pub/balogh-laszlo-sipos-farkas-f-ii-nemzetkozi-tud-konf-2020-ptektk-pecs-2020-4257.

7. The Relationship between Industry 4.0 & Circular Economy in the context of Sustainability.

IV. BBS International Sustainability Student Conference Proceeding. Budapest Business School, Hungary 2022

http://publikaciotar.repozitorium.uni-bge.hu/1865/