DOCTORAL DISSERTATION

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Industry 4.0 adoption challenges in Jordanian pharmaceutical manufacturing

PhD. DISSERTATION

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Abstract

Industry 4.0 adoption challenges in Jordanian pharmaceutical manufacturing

Case study: JAPM The Jordanian Association of Pharmaceutical Manufacturers

Technological development is one of the key drivers of change in the economic world order. This was not only the case of 2023. Since the 1700s, during the 1st Industrial revolution, the world has changed due to many impacts of the technologies from that event until now. We can consider ourselves in the age of the fourth industrial revolution: the age of digitalization, emerging technologies, and artificial intelligence AI. Industrie 4.0 or (I4.0) is the latest industrial technological development, born in the beginning of Internet of things (IoT) and cyber physical systems merging in the smart factories appliances. Much more of the German project (I4.0) was announced to the public in the Hannover fairs of 2011. Germany, USA and China and other developed countries have adopted I4.0 and it's road map was clear. This road map involved not just the manufacturing era, but it left impacts on schools, universities, and vocational training. In most of the developing countries, the I4.0 road map is not clear yet. However, the process of adopting Industry 4.0 or any new technology in any sector of the economy has drivers and challenges. In developing countries, the challenges are overcoming the adoption of I4.0 emerging technologies. One of the challenges is the human ability to meet the new market requirements. Therefore, the aim of this thesis is to help the Jordanian manufacturing system to adopt the I4.0 emerging technologies by filling the gap of skills and competencies, in terms of I4.0. On second instance, to raise awareness among the decision makers in Jordan to drive this adoption. This study concluded that there is no real adoption of I4.0 technologies in Jordan, as well as some studies did, four to be exact. They highlighted the challenges in general. Also, they have recommended further studies in the pharma industry. But only this dissertation cleared out what exactly are those challenges and suggested a real time solutions. By reviewing the Industry 4.0 excellency center project in Jordan, surveying the Jordanian pharmaceutical manufacturing and reviewing the necessary skills required by I4.0 the study resulted in new findings. The relevance of the results of this study is meant to be headed for the decision makers in Jordanian manufacturing, as much as these results can agree in different markets, industries, and countries, respectively, to the corporation sizes and capital the case study. The objectives were done by using a mix of three different scientific methods. In the first chapter, the study motivation's aims and problem were explained; followed by the study model, questions, hypotheses, and the methodology. Chapter two brings the literature review of the study topic areas. And chapter three holds the empirical part of the study, of both quantitative and qualitative methods. Chapter four contains the dissertation new scientific results, conclusions and recommendations based on the relevance of the scientific results.

1. Introduction

It is undeniable that the world's economy has changed over time due to technology, but in the last decade this was a rapid change due to more complicated emerging technological developments. Emerging technologies started at the dawn of steam engine, as a result of mathematics and mechanical engineering in the 1800's, which is known as the Industrial revolution or Industry 1.0. Moreover, the mix of the mechanical and electrical systems is called the second industrial revolution. Then computers and internet created the third industrial revolution 1900's (Erol et al., 2016). In the end of the third industrial revolution, web 2.0 came to place brining the cloud computing power to generate and share more and more data. According to the book *Das internet der dinge*,2005 was the year that brought the technology of IOT, Internet of Things, and by things it means either machines or any other object that, connected to the internet, shares info on the cloud without human interaction (Fleisch & Mattern, 2005). IoT, big data, cloud computing, AI and many more technologies were the formula behind the smart factory and I4.0. Industrie 4.0 was the concept of the German government projects to enhance the complexity of production in the manufacturing era, to meet the requirements of the economy, and fulfill the new consumer behavior desires (Alcácer & Cruz-Machado, 2019). Fully automated factories using the technologies of Cyber physical systems (CPS), IoT and the rest of the I4.0 technologies was named *smart factory* (Gilchrist, 2016). I4.0, which was firstly mentioned at the Hannover Fair 2011, indicated a programme for the digitization and strategic development of the German industry (Kagermann, Helbig, et al., 2013; Wadan et al., 2019). This project has spread worldwide with different names, as *Made in China 2025*, *Smart factory*, *Intelligent industry,* and *Advanced manufacturing* (Wübbeke et al., 2016). Over time, the Industrial Revolutions brought more comfort and at the same time complex challenges, but not only for the policy makers. Labor market participants are also facing these challenges.

Since the first industrial revolution the world labour had to adjust to cope with the new requirement. I4.0 had a technological or digital influence on the labor market. Industry 4.0 has affected many activities, replacing humans for machines. We can see it during the check-in process at the airport, in a supermarket's self-checkout machine, and many other conventional activities. Previous studies confirmed that only highly skilled and qualified human resource will be able to control Industry 4.0 technologies (Hecklau et al., 2016). Adopting I4.0 in manufacturing era comes with advantages and disadvantages that need to be faced, so its disadvantages can become economic advantages. Germany and other developed countries that are leading the new world economy have a clear vision of the skill gaps and other gaps caused by the I4.0 adoption. Challenges are being faced since the start of the new project (Le et al., 2020; Lukowski et al., 2021). But in other countries, the vision of overcoming the challenges that come from the adoption of I4.0 is not yet clear. To adopt I4.0 technologies, the challenges are not only related to handling the lack of skills required by the human workforce to operate I4.0, but energy cost and consumption and cyber security are some of the biggest challenges even for developing countries. In Jordan for example there are too many challenges to be faced to adopt this new revolution. However, this adoption is not a matter of choice any more where indeed the economy must be adjusted to cope with the new world order (Shqair & Altarazi, 2022). Many challenges will be faced with this adoption. The objective of this dissertation is to reveal those challenges and suggest recommendations and solutions to overcome those challenges. When facing great transformations within a social context, it is necessary to consider the possible impediments, which will be followed by techniques to solve those impediments. This discussion leads to contribute to the study aim by filling the lack of skill gaps in the Jordanian labor market participants in terms of I4.0 adoption challenges.

Previous studies highlighted the challenges of adopting some of the I4.0 technologies in the banking and construction sector as well as SMEs by surveying top management levels to exam the maturity of the manufacturing era in Jordan (Al-Zyadat et al., 2022). In the recent years, with the influence of COVID-19 crisis, an accelerated dependency on those new technologies happened; the human power was required to have a new set of skills and competencies (Alhloul & Kiss, 2022). I4.0 related skills and competencies are more than just performing a task or resolving a problem in each field, but it is the capability to meet complex demands including interpersonal attributes to be self-driven for lifelong learning in each field (Ananiadou & Claro, 2009; Kipper et al., 2021).

This dissertation consists of four chapters, the first chapter which begins here to explain the study motivation, problem, aim, study model, hypotheses, and the methodology. Chapter two is the literature review which discusses the following topic areas: the first, explaining of the main technologies of I4.0 and operator 4.0 in a way a decision maker can understand it, rather than deep technological details; the second part will explain what are the I4.0 technologies that are being used in the pharmaceutical manufacturing; the third part will elaborate on the Jordanian economy, Jordan IT infrastructure & internet coverage, the Jordanian pharmaceutical manufacturing; then a subchapter will discuss the interviews of the I4.0JO, an EU funded project to adopt I4.0 in Jordan. Fourth part will contain the skills and competencies that are associated with I4.0.; chapter three brings the quantitative analysis of the survey collected from the pharmaceutical manufacturing top management in Jordan. Further explained in the methodology part; chapter four will contain the new results evaluated in the thesis, its limitation, recommendation, conclusion and discussion. In this way the decision maker in Jordan can go through what are the I4.0 concept and technologies, as well as which I4.0 technologies are being used in the Pharma Industry.

1.1 <u>Study motivation, problem, and gap</u>

In this thesis the main argument is about adopting I4.0 emerging technologies challenges in the Jordanian manufacturing in general and in the pharma industry. The Jordanian pharmaceutical Industry is considered be the most advanced in the Jordanian manufacturing era, yet there is no real adoption of I4.0 in any emerging technologies in this sector. Moreover, Industry 4.0 is the place where only high skilled and qualified work force can operate and use those technologies. Missing citation With I4.0 it became necessary to create not only many new jobs and career paths but also the disappearance of many job profiles. This leaves negative impact on the workforce generation existing in the labor market. Unemployment rate in Jordan have reached 50% among youth in the last two years; even without a real I4.0 adoption. Another issue faced is that AI is already replacing Human power in too many fields after covid-19 crisis which led to more dependency on the digitalized system; those two statements bring to light two issues or two more motivations that contribute to this thesis' aim. And those can be seen embodied in the following questions.

<u>Thesis questions</u>

<u>RQ1</u> What are the challenges preventing the adoption of Industry 4.0 in the Jordanian pharmaceutical manufacturing?

RQ2 What are the skills and competencies that will allow human factor in Jordan to cope with Industry 4.0? And what of those skills can be valuable in the contingency plans if Industry 4.0 systems fails?

RQ3 What recommendations should be given and to whom they should be headed to overcome the challenges of Industry 4.0 adoption?

Thesis objectives

To achieve the thesis' aim (contribute filling the gap of lack of standards and lack of skills to adopt I4.0 in the Jordanian pharma Industry) the following objectives were set and accomplished step by step.

- Explain the Industry 4.0 main technologies.
- Explore the Jordanian economy in terms of industries and manufacturing.
- Analyze the Jordanian pharmaceutical manufacturing.
- Explore the internet coverage in Jordan.
- Review the related and needed skills and competencies related to Industry 4.0.
- Analyze and review Industry 4.0 EU funded project in Jordan suing qualitative method.
- Reveal what are the real Industry 4.0 adoption challenges and relate them to the Jordanian pharmaceutical manufacturing ear using quantitative method.
- Discuss the results of the study with other results of related studies in other countries.
- Recommend set of practical activities to overcome the challenges of adopting Industry 4.0 emerging technologies in the Jordanian pharmaceutical manufacturing.

Research model and thesis hypotheses

Adopting Industry 4.0 is the latest fashion in mass production since 2011 in developed countries like Germany, US, China, and many other countries. But now, other developing countries started to have grants and funds to adopt those new emerging technologies of the smart factory, automated manufacturing of Cyber physical systems in connection with the IoT. In many studies, the adoption of those technologies was assessed and examined using qualitative and quantitative studies. Those studies used many models to explore the challenges and drivers. The most popular was model Technology Acceptance Model TAM (Davis, 1989). In this study, two models were used: TAM and MBSE. MBSE is a part of a system engineering process life cycle, which consists of two approaches: one which is document based, and another one that is model based (Model-Based Systems Engineering (MBSE)(Suri et al., 2017).

Table 1 Challenges associated with adoption Industry 4.0 in the pharma manufacturing.

Challenge	Category	Source (s)
Upfront investment/cost	Lack of financial means to implement Industry 4.0 manufacturing technologies.	(Walendowski et al., 2016b)
	Requirement of continuous training and education for the work force.	(Kagermann et al., 2011; Kagermann, Wahlster, et al., 2013a)
	Energy costs to operate Industry 4.0 technologies.	
	Lack of infrastructure means of internet and energy.	(Luthra & Mangla, 2018a)
Legislation and standards	Lack of standards of communication methods of Industry 4.0 ex (IoT).	(Shqair & Altarazi, 2022)
	Lack of governmental (import /export) standards complying with Industry 4.0 technologies.	(Adimuthu et al., 2022)
	Lack of cyber security standards and laws.	(Kwahk & Lee, 2008; Rhee et al., 2010; Walendowski et al., 2016b)
	Too few investment promotions standards to adopt industry 4.0.	(Stentoft et al., 2021)
	Lack of (blockchain) cryptocurrency standards and laws.	(Musamih et al., 2021; Yadav & Kumar, 2023)
Management	Lack of understanding of the strategic importance of Industry 4.0.	(Geissbauer et al., 2016; Stentoft et al., 2017)
	More focus on operation at the expense of developing the company (ambidexterity).	(Haug et al., 2011; Horváth & Szabó, 2019; Rhee et al., 2010; Stentoft et al., 2021)
	Awareness and Change Resistance at the top management level.	(Birkel et al., 2019)
Workforce	Lack of qualified work force.	(Probst et al., 2017)
	Lack of employee readiness	(Kwahk & Lee, 2008; Walendowski et al., 2016b)
	Lack of understanding the relationship (human-machine)	(David, 2015; Walendowski et al., 2016b)
	Awareness and Change Resistance in the work force	(Birkel et al., 2019)
Adoption risk	Lack of data protection (cyber security)	(He et al., 2016)
	Risk of Compatibility with the pharma Regulatory Affairs of FDA, EMA and MENA standards	(Ding, 2018)
	Pharmaceutical continuous manufacturing system failure risk	(Jelsch et al., 2021)
	Unemployment rate increasing risk	(Szabó-Szentgróti et al., 2021)

Modified table based on drivers and challenges of Industry 4.0 adoption in manufacturing (Shqair & Altarazi, 2022; Stentoft et al., 2021)

Table 1 showing what are the factors of each challenge based on the literature review. Using both MBSE and TAM models to accept and adopt new technologies. In the study model figure 1 we can see that the independent variable is *Adopting Industry 4.0 emerging technologies in the Jordanian pharmaceutical manufacturing*, those technologies are different from one study to another. In this study the following represents the main I4.0 technologies (Industrial Internet of Things (IioT) (Alcácer & Cruz-Machado, 2019), Cloud Computing (CC) (Mell & Grance, 2011), Big data (Bag et al., 2020), Simulation(Alcácer & Cruz-Machado, 2019), Augmented reality (Longo et al., 2017), Additive manufacturing or 3D printing (Chang et al., 2018), Horizontal and vertical systems integration (Alcácer & Cruz-Machado, 2019), Autonomous Robots: refer to Artificial Intelligence (AI), Cybersecurity CS (Stachová et al., 2020). Cyber-Physical Systems (CPS) (Samad & Annaswamy, 2011)) However, Block chain technology was explained because of its relation to I4.0 technologies and the idea of decentralized cryptocurrency is associated with some of the pharmaceutical manufacturing in terms of consumer support and/or loyalty matters (Musamih et al., 2021).

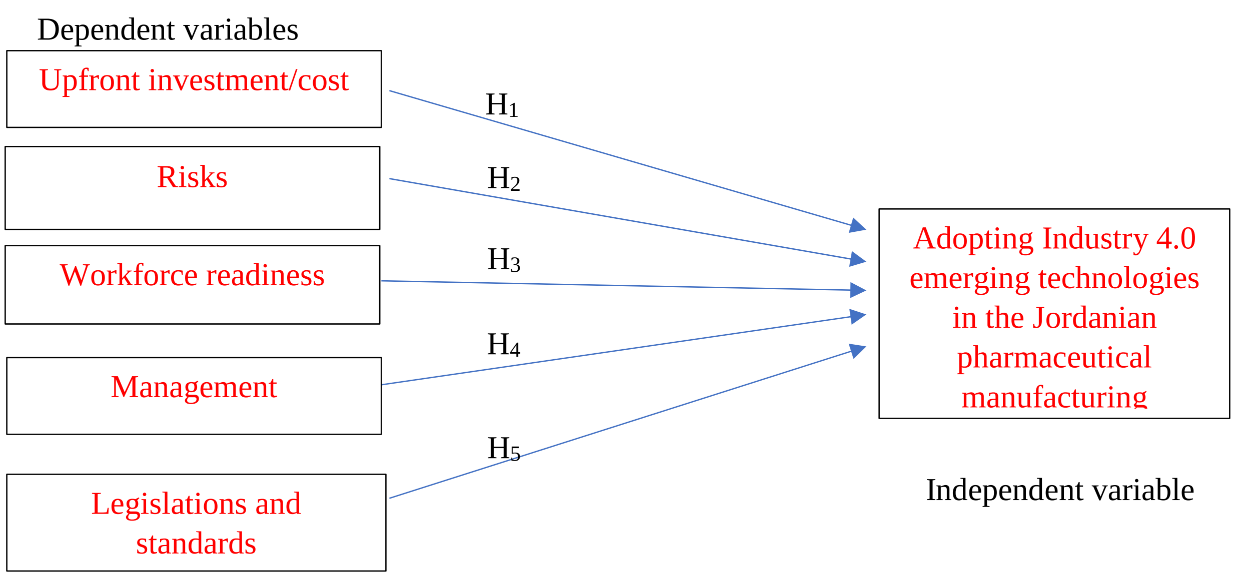


Figure 1 modified study model based on the literature review look table number 1 source (own contribution)

Using TAM and MBSE resulted in the drawing figure 1, showing the dependent variables on the left side of the figure. From this point we can relate the effect and initiate the dissertation hypotheses.

Study hypothesis

H1 Industry 4.0 upfront investment/cost has a negative effect on adopting the I4.0 in the Jordanian pharmaceutical manufacturing.

H2 Adopting Industry 4.0 in the Jordanian pharmaceutical manufacturing is more likely to increase the risks and leave a negative impact on adopting this technology.

H3 Workforce readiness to meet the operator 4.0 requirements will decrease the ability of adopting Industry 4.0 in the pharmaceutical manufacturing in Jordan.

H4 Pharmaceutical manufacturing management decisions have a negative impact on adopting Industry 4.0 emerging technologies in the manufacturing in Jordan.

H5 Legislations and standards in Jordan have a negative effect on adopting Industry 4.0 in the pharmaceutical manufacturing industry in Jordan.

1.2 Thesis Methodology

This dissertation has followed the following methodologies to accomplish the objectives of the study. This methodology is a hybrid method that depends on bibliometric analysis, systematic literature review, qualitative analysis using interview approach, and quantitative analysis using the tool of survey. The following steps were taken respectively where each step was required for the next step of the research:

1. Collect secondary data using the methods of bibliometric analysis to find the most important, and top cited documents; on the online academic science databases (Scopus, Elsevier, Web of science and google scholar) by using (Vos viewer, excel software) to visualize and then analyze the results using a systematic literature review. In reach database advanced search was used. The occurrence of the keywords in the document title, abstract and keywords at least five times was the selection factor and the factor of analysis was the author keywords. Also, using * in the search query allows the computer to detect all the related keywords which start with the part of the word before the * string sign. All the search inquiries had the time span of the last five years, except for the skills search were excluded because of outliners in the database.
   a. Industry 4.0 main technologies (Industry 4.0) OR (fourth industrial revolution) OR I4.0 OR (smart factory) OR (advanced manufacturing)) AND (emerging

technologies) OR (Industry 4.0 technologies) OR (IoT*) OR (CPS) OR (AI) OR (3D printing)).

b. Industry 4.0 in the pharmaceutical manufacturing in the world not only in Jordan ((“Pharmaceutical”) OR (“pharma*”)) AND ((“industry 4.0*”) OR (“fourth industrial*”) AND (“manufacturing*”)).

c. Skills and competencies required by Industry 4.0 (((“human factor”) OR (“operator”) OR (“smart operator”) OR (“workforce”) OR (operator 4.0)) AND ((“Industry 4.0”) OR (“4^{th} industrial revolution”) OR (“smart factories”) AND (“training”) OR (“education”)) AND ((“skill*”) OR (“Competenc*”)).

d. Jordan economy, pharmaceutical manufacturing in Jordan, Industry 4.0 project in Jordan (Industry 4.0) AND (Jordan) in this search using Industry 4.0 only instead of the synonyms resulted in 4 instead of 3 documents using I4.0 synonyms.

e. This part of the thesis, including its documents, had a criterion of having more than five citations. Documents in English and, in some cases, in German were used not ignore any important citations. The document must be published in peer reviewed journal with impact factor.

f. Each database has a certain extinction file which must be used in Vos viewer according to the software manual. For example, Scopus database must be in the file extension; common separated values (CSV) please review (van Eck & Waltman, 2011) for more.

2. Collect secondary data about the statistical reports about Jordan to describe and map visualizing of the internet users, internet maps and manufacturing maps which is in relation with the industry 4.0 project in Jordan. Here the data was collected online using all the published data of the *Department of Statistics/Jordan*, and the *Minister of Digital Economy and Entrepreneurship/ Jordan*.
3. Formulate the study hypotheses based on the literature review; they were conducted using the above results of step 1&2.
4. Design a modified conceptual model based on the TAM and MBSE model to determine what are the main challenges that influence the adoption of I4.0 in the Jordanian economy.

5. Investigate industry 4.0 project in Jordan using (qualitative method) in-depth interview with the mangers of Industry 4.0 project in Jordan; to highlight what are the real challenges that holds the Jordanian pharma manufacturing from adopting the emerging technologies of Industry 4.0. only two mangers were interviewed: one face to face and the other was done using Microsoft teams, which was done during August and September of 2022. More details about the project and project partners will be in the Industry 4.0 project in Jordan part of the study.
the analysis of the interview was made using thematic analysis to match the answers of the experts to the study questions. In this type of data collection there is no clear minimum or enough participants in the interview where in fact the study community in the qualitative research part was the number of the 4 organizations participating in the project (Bernard & Ryan, 1998). Applied thematic analysis were used to analyze the interview textual data which was generated from audio files in first place according to(Guest et al., 2012).
6. Quantitative method was used to survey the study community, test the study hypotheses and meet the objectives of the study. The study tool “questioner” was published in between the time of October 1st and November 10th, to ensure the data validity of publishing time of 40 days only (Study tool questioner look annex number).

- The thesis survey was built based on the developed model that depends on the literature review (look study model table 1) and the interviews with the EU funded project Industry 4.0 managers in Jordan.
- The study tool (questionnaire) was tested before it was posted and sent to the targeted sample. The testing was done by 5 managers from other industries to assure its reliability, noted that those 5 were not included in the analysis or as part of the study.
- The characteristics of the sample and questionnaire respondents are described in this thesis (analysis part) using descriptive statistics. The “Statistical Package for Social Science” (SPSS.24) was used to analyze the structural equation modeling and test the study hypotheses.
- In this step a more detailed description will be provided about the analysis part of the thesis which makes it easier to follow the results tables, according to which statistical test was used in each of them.

- Study population and sample of the thesis:

  210 questionnaires were obtained, and after the initial sorting of these questionnaires, 10 questionnaires were excluded due to the inadequacy of these questionnaires for accuracy and reliability. Thus, 200 questionnaires were used in the statistical analysis process (please note that 5 responses of validity test were not included in 210 questionnaires).
- The study population included human power at the senior management levels in Jordanian pharmaceutical companies, and to ensure the achievement of the objectives of the study, the study was carried out on the companies listed in The Jordanian Association of Pharmaceutical Manufacturers JAPM, numbering (14) companies.
- The study sample was selected using the appropriate convenience sampling method, as an electronic questionnaire designed through Google forms. It was distributed and shared through social media and by e-mail with workers at the supervisory and administrative levels in these companies.
- The statistical methods used in the quantitative analysis:

  To test the hypotheses of the study and achieve its objectives, the researcher conducted through the statistical package for social sciences SPSS appropriate statistical tests by employing the following statistical methods:

  a- Frequencies, percentages, arithmetic means, and standard deviations in order to extract the values of descriptive statistics.

  b- Exploratory factor analysis to detect structural validity in the questionnaire items.

  c- Cronbach alpha stability coefficient test to measure reliability.

  d- Normal distribution test to verify the normal distribution of data.

  e- Variance inflation factor test to ensure that there is no multi-correlation between the independent variables.

  f- Multiple linear regression analysis to test hypotheses: Where was this test conducted, after making sure that its statistical assumptions were met, that is, the presence of linearity and the normal distribution of the data, and therefore it can be performed because it is one of the parametric tests.

2. Literature review

Archaeology can prove that no human group was able to survive without the use of tools (Tomasello, 2018). Tools, over time, have changed. In the early stone age, tools ware only a sharp stone to help human cut and hunt. Nowadays, in the 21st Century, tools have changed to the development of cyber physical systems (CPS), Internet of things (IoT) and Artificial intelligence (AI). Those are some of the main technologies of the latest Industrial Revolution. This is the fourth industrial revolution (Alcácer & Cruz-Machado, 2019; Kagermann, Helbig, et al., 2013). However, the perspective of this thesis is to have humans in the center of industry, but are we developing fast enough to cope with this revolutionary industrial application and technologies? The answers lie down in the deep understanding of this development. How has it started? And how were we able to reach it?

In fact, humans started to use tools in their lives to survive. Survival requires change over time, as the change of needs. For an easy understanding, we can refer to Abraham Maslow's hierarchy pyramid of needs. This pyramid describes that need of water, warmth, rest, and food are the basic needs of humans. Then, human needs safety and security for himself before the others. These are immediately followed by the need for feelings of belongingness and love, and, after that, the feeling of accomplishment and at the top of the pyramid, self-actualization. This psychological theory developed by Abraham Maslow can explain how humans have used tools also in the pursuit of those needs (Maslow, 1974).

Archology again couldn't really tell how Petra, El Castillo, the royal cemetery at el-Kurru and Khafre ware really built without the use of the advanced tools of our times. (Dunham, 1956). However, simulation and imagery processing techniques could draw a scenario of how a man-made pyramid was built, but not in a practical way to reconstruct another using human power, especially if we took occupational health and safety in the workplace in consideration (Brunner et al., 2010; Dunham, 1956). This statement relates that each civilization in the history had their unique knowledge and engineering practices. The same statement admits that unique parts died with those civilizations.

Moreover, in 2022, the knowledge that the academic research is aware of is in an absolute ignorance of the top leading organizations and military researches due to the lack of access to this information. This knowledge has witnessed no real concept of energy conversion before 1736 James Watt. Yes, we could use the wind power to sail before, and, yes, watermill was used to grind wheat. But why? Watt became known as the father of the industrial revolution from developing the steam engine based on Thomas Newcomen work (Robinson, 1970). James Watt was able to convert energy into an isolated system (Thurston, 1884). By saying isolated system, it refers to the Energy Conservation Law which states that "The total energy of an isolated system remains constant; it is said to be conserved over time $K_1+U_1 = K_2+U_2$ [1]". A theory depends on this law states that this energy in that system can't be destroyed or created but it only changes from one form into another or is transferred from one object to another (R. T. Jones, 1974). So, what Watt did was the conversion of the heat energy engine of Newcomen to a mechanical energy. Heating water pressures the steam to create mechanical movement of a piston. This was the steam engine. Watt didn't use only the mechanics of Newcomen models to create the steam engine but also the algebra mathematics of al-Khwarizmi c. 780 – c. 850 that his grandfather taught him (Muirhead, 2022; Robinson, 1970). The steam engine was the beginning of the first industrial revolution with not only its incorporation into daily life, in mass production, but rather the use of this engine in transportation and logistics (Bogart et al., 2017). This first Industrial Revolution, which I would rather name the *Mechanical Revolution,* was where, in fact, the use of the mechanical method began. This first revolution of the mid of 1700's until the mid of 1800's has created a huge migration from the east to the west and from Europe to the United States of America.

In the second Revolution, electricity was combined with the mechanical methods in order to create the first concept of mass production. The combination of electricity and mechanical methods first appeared in the conveyor belts. There was a huge debate about when and where was the real first use of conveyor belts. It is known that the conveyor belts are the part of any manufacturing process in all the industries we have been witnessing since the late 1800s. The first real use of conveyer belts in coal industry was by the British army, invention accredited to Thomas Robins, in 1890. But this invention and the use in coal industry was accredited to Richard Sutcliffe in 1905 (Hoshimov et al., 2018). Moreover, textile and food industry started

[1] K_1 = initial kinetic energy, U_1 = initial potential energy, K_2 = final kinetic energy, U_2 = final potential energy

to use conveyor belts in the mid1880s. It is worth of mention that technological transition resistance didn't only happen in present times, but in the English history, during the fist industrial revolution, groups started a war against the machines of the period. They were called the luddites (Randall, 2002). It is believed that this name was originally formatted from the name *Ned Ludd*, a legendary weaver supposedly from Anstey, a village in England. This can be considered the first human-machine relation. In both drivers and barriers (challenges) of the industry. Even nowadays the name of the luddites is referred to the people who dislike the technologies, where some authors agree and others don't with this movement (S. E. Jones, 2013). We can relate this first human-machine relationship to the need of change, and the need of a new set of skills and competencies to have humans as the center of I4.0. However, automobile industry and trains only helped people to move to other spatial areas in a more efficient way reducing time and effort to carry merchandise and cargo around the world (Bogart et al., 2017). But before the arrival of industry 3.0. one discovery came to change the ratio of human population. This discovery was by Alexander Fleming in 1928, London, when he discovered penicillin(Bennett & Chung, 2001). That relates to the issue of worldwide overpopulation which, as we can see, started in India and China. Those two nations were known by their developed medicine practices over history, which can be one the reasons of their overpopulation. This claim can be supported by the fact that when the antibiotics started to be used in the medicine practices, death ratio declined.

The first two industrial revolutions, according to the facts mentioned above, started in the United Kingdom. In here we can see the first shifts of the 1900's. Development in the medical and transportation fields, which required more and more raw materials such as coal, steel, and other valuable resources. Developed countries started to search for more materials, which led to the discovery movements by the great players in the economy at the time. These discovery movements were not only done by the United Kingdom but also by other developed nations as Europe, China, Japan, and the United States of America. This was the World War's first provoking movements. After the two World Wars took place leaving many tragedies to humankind. Political history has reached a common ground on many treaties and sanctions between the world wars quarrels. After that period, the world started to recover, using the inventions not for war but rather to increase the comfort level of the people, creating a new path to provide services and products. However, by using the technologies of the Industry 1.0, 2.0, and 3.0, the quality of life improved, especially with the pharma production using the techniques and methods of those technologies.

In the 1900's, the use of electricity improved until we reached the creation of computers. The computer was created with the help of the mathematicians. They used programmable math computerized methods present at the time of World War as well. This invention came from the named "father of the computer", Charles Babbage, in 1832, even before he invented the mechanical computer, or what it was called at the time, the analytical engine (Halacy, 1970).

December 10 of 1945 was the date when the giant brain was introduced: the ENIAC (Electronic Numerical Integrator and Computer), a huge device which weighs up to 30 tons. It was designed by John Mauchly, Ursinus College physics professor, and J. Presper Eckert of the University of Pennsylvania. In the U.S. it was believed that this invention was part of a secret military project of the U.S army, announced to the press in 1943, as a project of half a million dollar at the time (Metropolis, 2014; Stuart, 2018). The development of the computer from a basic calculator helped humans to solve in 30 seconds a large class of numerical problems that humans needed more than 20 hours to solve. In here we can see how the steam engine helped people to move around the geospatial areas of the world in less time (Bogart et al., 2017). Then the antibiotics helped increasing the human life expectancy (Bennett & Chung, 2001). The computer came in place to reduce the problem solving time. This fact can be considered the beginning of the third industrial revolution. But still at the time 1945 the computer help was not really used in the manufacturing. During the period between 1945 and 1971, computers were too expensive and huge to be used in any organization, and, more important, the issue of cooling such a device, that generates heat by solving numerical problems, was a big one. But with the development of the so-called microchips the world has really changed at the time. Yes, indeed telecommunication was produced before the age of 1971 but still computers were not really involved. In 1971, Intel corporation produced the Intel 4004, a chip that can be considered the first microprocessor (Aspray, 1997). This was done by replacing silicon by magnet in the semiconductors. The semiconductor, which we will talk about later once we reach the end of the fourth industrial revolution, was a huge transformation, creating the fourth generation of computers. This new version was smaller, lighter and required less materials to be produced, and, the most important, less cooling is required which means less electricity; this is considered to be the beginning of the Third Industrial Revolution, in 1996. Now semiconductors help creating more and more computer generations that requires even less energy and materials.

The accumulative knowledge of the Industrial Revolutions created the first automated system, the first programmable logic controller (PLC) Modicon 084. This system was a combination of computer, electricity and mechanical applications, started by the American mechanical engineer Dick Morley in 1968, as the top manager of development team working for General Motors (Segovia & Theorin, 2012). After that, the internet and the World Wide Web came to change everything. During the time between 1996 until 2005, the internet dominated big part of communication using the World Wide Web, which allowed the world to become a small village (Leiner et al., 2009).

In 2005, *Internet der Dinge* (Fleisch & Mattern, 2005), a German book that explained the concept of Internet of Things, or IoT. In this context, things could mean anything: a human or a device that is connected to the internet. With the use of smart devices or things connected using the internet without the need of human interaction to organize the connections, technology got to the point that allowed the creation of a fully automated manufacturing systems called the smart factory (Gilchrist, 2016). In 2011, in Hanover, the creation of cyber physical systems was announced to the world as the new industrial revolution (Kagermann et al., 2011; Kagermann, Wahlster, et al., 2013a) 4.0. So, Industry 1.0 to 4.0 is the combined knowledge of them all; mechanical, electrical, computerized systems, IoT, AI and cyber physical system CPS and then renewable energy to operate fully automated. But what was different in Industry 4.0 and the rest? The author believes that I4.0 has two important things that strongly changed the world: AI artificial intelligence, and IoT (Anderl et al., 2014).

But what is the relationship between the world disasters (man-made or natural) and Industrial revolution 4.0? Industry 4.0 emerging technologies can bring the mitigation of those crises or it can be the tuning point of a massive disaster. What can determine whether it would be a success or a failure is the human-machine relationship. Human-machine relationship is dependent on both AI and IoT (Kadir & Broberg, 2021). But to understand this relationship and not to avoid any important parts of Industry 4.0, now, this study is going to review those technologies one by one.

Worth of mentioning that this topic of industry 4.0 became too popular among academic researchers in the last ten years but what made this revolution a new world order of digitalization is not only the smart manufacturing but more importantly Covid-19 crisis. It is believed that COVID-19 was a push to implementation of I4.0. It also it opened our eyes to the fact we have used it to overcome COVID-19 crisis (Alhloul & Kiss, 2022; Nickinson et al., 2020). In the different researches, we can see that Industry 4.0 emerging technologies are huge, and many authors presented 14 different technologies. In this thesis, Industry 4.0 will be considered through its eleven main technologies and one concept about Operator 4.0 (Gilchrist, 2016; Salkin et al., 2018).

2.1 What are Industry 4.0 emerging technologies?

Understanding the real concepts of the technological development of the current times can help the decision makers in profit and nonprofit organizations. Understanding how things work can help decision makers think of what solutions could better respond to changes in the organization environment, whether these are internal factors or external factors, not only to increase profit but also to tackle the challenges of change that the economy is bringing with each period over history. Understanding how we have reached this point is important as well to help realizing the base knowledge of those systems. It was mentioned that each time in the industrial revolutions there was one invention that changed the monopoly of the world economy and order. But, this time, with the industry 4.0, there are ten main inventions regardless of the dependency of those technologies on other old ones or on each other's . Still, each one of these ten technologies is important to explain the advances and can't be taken apart from the smart factory conception. Which is the application of the full automated manufacturing systems.

In 2011, the German state announced the 'High-Tech Strategy 2020' work program, which periodically produces billions of euros away for the extension of cutting-edge technologies. As one of the ten proposed plans, the 'Industrie 4.0' represents the German goals in the industrial area (Kagermann, Wahlster, et al., 2013b). Industry 4.0's expectation of production involves overall integration where each production element exchanges data autonomously, initiates actions, and independently controls itself (Monostori, 2014a). Small, decentralized, and digital production networks act without human intervention and control their operation independently according to their environmental changes, and requirements are the critical elements of this production plan to create intelligent processes (Hofmann & Rüsch, 2017; Kagermann, Wahlster, et al., 2013a; Lanza et al., 2015).

Table 2 Production development overview

	Past	Industry 3.0	Industry 4.0
Connection Technique	Analogue	Internet and Intranet	IoT & CPS
Concept	Neo-Taylorism	Lean Production	Smart Factory
Solution	Mechanization and Automation	Automation and Computerization	Virtualization and Integration

Source (Mrugalska & Wyrwicka, 2017).

In the structure of I4.0, the concept of “smart” becomes fundamental, but accurate description is not easy to obtain. However, a likely description of this idea can be connected to independent devices that can interact in real-time and cooperate with other intelligent devices, in an intelligent environment, make decisions and conduct activities based on the obtained data (Kagermann, Wahlster, et al., 2013a). The concept of Industry 4.0 is a new approach that mixes both digital and physical worlds. Criteria can further specify the main aspects of industry 4.0: (1) Smart Factory, (2) Smart Products, (3) Business model, (4) Customers. Researchers and firms take different perspectives on industry 4.0 (Qin et al., 2016). Industry 4.0 is a new production paradigm, which concentrates heavily on the creation and transformation of smart products and processes using intelligent machines and the transformation of conventional production systems into smart plants. Explaining this needs to illustrate the smart factory in one figure, which can explain how the smart factory works. This figure is aimed at the designated study to show the relation of IoT which is the nervous systems of the smart factory look figure number 2.

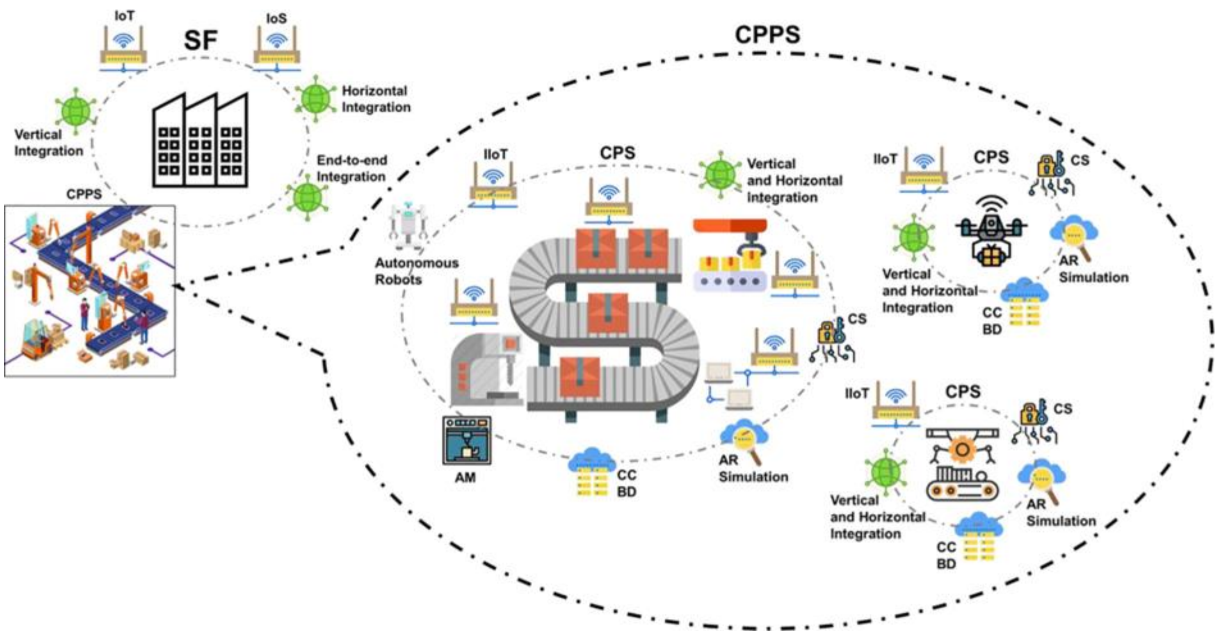


Figure 2 Smart factory of Industry 4.0 source *(Alcácer & Cruz-Machado, 2019)*

The Industrial Internet of Things (IioT)

Industrial internet of things could be defined based on the word itself if we divide it. Then the internet means the network of networks. Which is a global system that meant to serve the connectivity between computers (users) worldwide, and this network uses Standard Internet Protocol suit (TCP/IP). *Things* could be a person using a computer or just an object which is connected to the network. This technology is widely used in the world now in many applications that are part of our daily life, as well as all the levels of economy. We can see this technology used in smart homes, cars and all the objects which are connected to the network (Mourtzis et al., 2016). We already can see this technology in the door passes and many other using the Radio frequency identification RFID, Wireless Sensor Networks. Some authors have defined the IOT as the connectivity of anything in any time and any place using any path of the network (Sezer et al., 2017). In figure number 3, we can see the timeline of IoT over time starting with RIFD reaching to the complexity of what now we can witness as the Age of the fifth generation. (Madakam et al., 2015; Matthew et al., 2017).

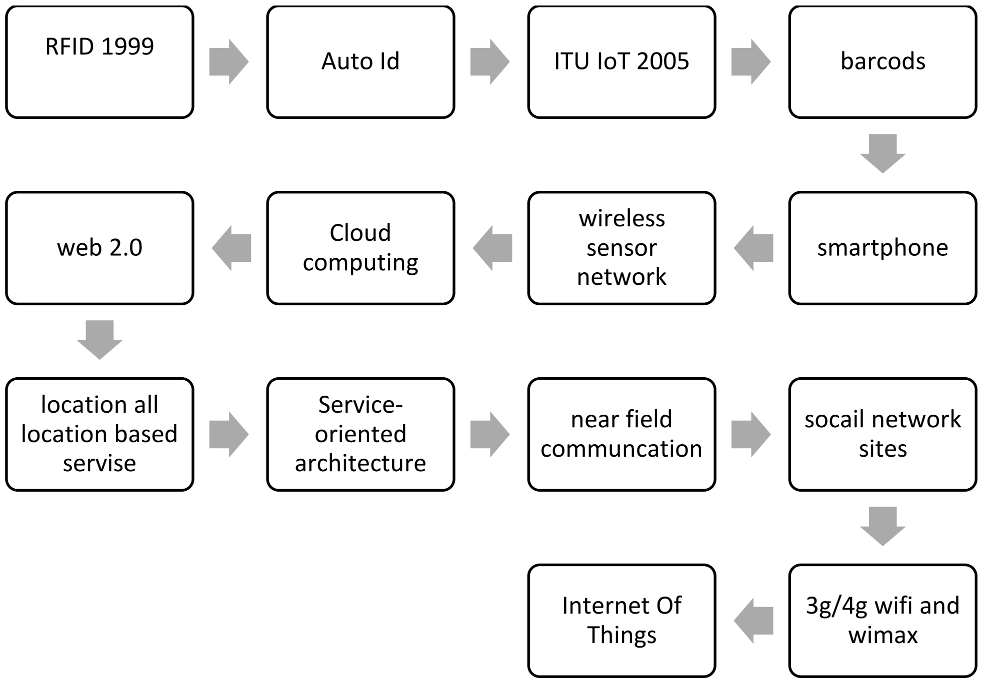


Figure 3 technologies associated with IoT source (Madakam et al., 2015)**.**

Internet of things is the technology that depends on data exchange between devices using more than one connection technology. IoT can be classified based on the logic of the connection type. Connection logic technology development in the IoT, over time, can be seen in figure 3. The Word of Things in the IoT concept is anything sends or receive data autonomous way which can be object or human that has a sensor sends and receives data using one or more of the IoT technologies shown above figure 3.

In the manufacturing era, IoT applications use the objects' sensors and connect them on a Wireless Sensor Networks (WSN), a middle channel through which they can share the data, the *middleware*. Then it needs to share it with the other objects, enabling the use of the cloud computing CC, by using a software to conduct the operation which was the Software Defined Networking (SDN) and those are the enabling technologies of IoT which allow devices to connect with each other in a fully automated way in smart factories and more applications as well (Alcácer & Cruz-Machado, 2019).

IoT can be defined as the ability of things to share data on the cloud using sensors and network between the human and other "*things*", which is considered as the one of the nerve system components. This technology can be found in the entire production system. It can be centralized, decentralized and heterogeneous (Madakam et al., 2015). IoT is operating based upon a design, which is established by a logical framework by layers to classify IoT technology and used to differentiate and classify Cyber Physical Systems.

According to several authors (Fleisch & Mattern, 2005; Hammoudi et al., 2018), IoT structural design can be drawn in four main layers.

1- ‘‘Sensing Layer” to sense the ‘‘things” status with a unique identity and to integrate, e.g., actuators, sensors, RFID tags as several types of ‘‘things”.

2- ‘‘Network Layer” to support the transferred information through wired or wireless network from the ‘‘Sensing Layer” to ‘‘Service Layer”, being the support’s infrastructure. This layer determines and maps ‘‘things” automatically in the network enabling to connect all ‘‘things” for sharing and exchange data.

3- ‘‘Service Layer” makes use of a middleware technology supporting services and applications, required by the users or applications. The interoperability among the heterogeneous devices is ensured by this layer, performing useful services, e.g., information search engines and communication, data storage, exchanging and management of data as well as the ontology database.

4- ‘‘Interface Layer” to make the interconnection and management of the ‘‘things” easier and to display information allowing a clear and comprehensible interaction of the user with the system.

IoT needs a real time and valid connection from the first layer to the fourth layer to serve the smart factory application. This happens by using different technologies of Industry 4.0. Nowadays, 5g in telecommunication technologies can provide a real time secure connection between the IoT sensors, by using satellite and microwave connection technologies to reach directly to the desired sensor, to always assure the connectivity, for example the GPS services and Autopilot driving mode in cars. As we can see below in figure 4, IoT has different category layers based on the connectivity level. Industrial Internet of Things (IoTT) which can be found in between robots closed manufacturing system, smart factory, on a higher level, includes logistics and transportation Internet of Services in term of manufacturing or any other activity. It uses the same means of technology and can be categorized under the name of IoT.

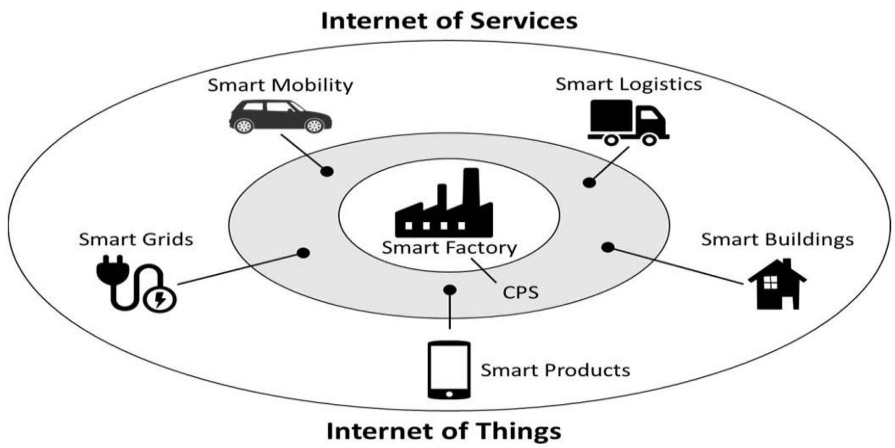


Figure 4 Intent of things on the internet of services concept source (Haller et al., 2009; Kagermann, Helbig, et al., 2013)

Cloud Computing (CC)

Cloud computing is about sharing the database with others on the cloud. In this case the other companies which are helping in providing services can reach to the database of a company. In this way, cloud computing is helping in data storage and management as well. Thus, cloud computing acts as a resource, pooling with rapid elasticity and measurable service, on-demand self-service, and wide network connectivity (Armbrust et al., 2010). The adoption of CC has several benefits related to cost savings, including the direct and indirect costs on the removal of IT infrastructure in the organization, the resource rationalization service by the dynamically scalable users consuming only the computing resources they use, or portability when using any type of internet-connected device, like mobile phones or tablets, and accessing from anywhere in the world. Cloud computing has four main types of access:

1- Public access which allows everyone to use this cloud service. This type can be found in public coding clouds where everyone shares and accesses the cloud.
2- Private access is permitted to only some private parties. this is the case of the companies that provide IT services to others on the cloud.
3- For Hybrid, the access is both private and public. The database offers some data for the public, but another level is granted only to a paying party.
4- Community is the type of access to a certain community with the same interests. The access is permitted to all the participants of that cloud with the same interests. This can

also be found in the coding clouds of programmers as well as other communities of industry or even gaming.

On all types and levels of the cloud computing, everything is treated as a service. Data on the cloud could be structured or unstructured data. But everything is treated as service, which means that everything shared on the cloud can be outsourced, even the IT infrastructure itself (Xu, 2012; Zhang et al., 2010). The following are the service types of CC:

- Infrastructure as a Service (IaaS) is an example of could computing services, and it is the mostly used. This service can allow SMEs to have larger storge and faster processing for the data. In most of the SME's the cost of infrastructure is high and there is no return of investment on having advanced IT infrastructure. One great example on that is TATA consulting services (TCS), in this organization they share the IT infrastructure as well as their services on the cloud. There is also another service which can be found on the CC which is the platform as a Service (PaaS).
- PaaS is the place where users can create and operate apps utilizing programming languages on cloud infrastructure. Scalability, high-speed servers, and storage are therefore possible. With the use of remote IT platforms, users can create, maintain, and deploy their own apps. The maintenance and availability of the resource are unimportant on this layer of services on CC.
- Software as a Service (SaaS) using the infrastructure of IT is considered as an example of this service.

Using CC in manufacturing, is important, in reducing costs. Using computer aid designs and EPR systems in the manufacturing is considered as all the services layers of CC which is XaaS, which means that everything is a service on the CC. Cloud Manufacturing (CMfg) is aimed and created to improve the manufacturing using CC. It has two different approaches. The first is CC in manufacturing industry as a manufacturing version of CC; it can be seen when a company is using two service levels of CC system, using software of another company in SaaS and using the plat form of a different or the same company in PaaS. In here we can see that CMfg is combining both SaaS and PaaS. One of the challenges that the pharma manufacturing companies are struggling with when to adopt Industry 4.0 technologies, and even universities as the experts of Industry 4.0 in Jordan have mentioned, is the lack of EPR systems as well as the lack of access to the developed software. In this situation, expensive access permissions and licenses are required. This way, CC and Big data can be the solution for a better product with less cost (Khan et al., 2019; Lu & Xu, 2017).

Big Data (BD)

Big Data or BD is a huge amount of data from different sources and/or contributors. This data, regardless of the structure type, has interconnected heterogeneous objects. The structure types of BD can be structured, semi-structured and unstructured. The same concept of cloud computing the data are generated from different parties on the cloud but in here BD is about sharing not only the data and the platforms but rather to share the storage of the devices. This type we can see also in the cloud computing service IaaS. Where, in fact, the use of other parties' storage can be categorized as infrastructure as a service (Manyika et al., 2011). The need for BD came after the need of more storage, as we can see in the GIS systems. In fact, there are some systems which generate thousands of terabytes every minute. The resolution of the data became better and, relatively, the space needed in the storage is higher. (Klein et al., 2015).

BD is complex and has huge volume. Yet, it is effective in the decision making for the top management where, in fact, it has innovative and cost-effective information processing methods. Many authors defined BD in terms of Volume, Variety, and Velocity, also known as the Three V's (Alcácer & Cruz-Machado, 2019; Witkowski, 2017). Then this concept was developed on a wider paradigm in terms of data management. And it is not 3V's anymore, now it can be characterized under the following dimensions: Veracity, Vision, Volatility, Verification, Validation, Variability, and Value (Alcácer & Cruz-Machado, 2019).

On manufacturing domain and at the BD process comprehension, it is the engineering aspects that give value to the BD analysis using its dimensions (Bag et al., 2020). These dimensions are dependent from each other, related with the relativity of BD volumes applied to all dimensions (Alcácer & Cruz-Machado, 2019).

On the manufacturing level BD needs analytics which is an essential key to digital manufacturing, with the help of CC for sure. In many examples we can see how small companies are generating data while manufacturing. This data can be analyzed by other parties depending on the access type of CC. With the help of IoT machines, users are able to share data which can be used in the machine learning process of AI. In this case we see an example of Tesla car manufacturing that has shared the source codes and designs of the electric vehicles to all the competitors. This type of data is generated not only by operators but also by the machines. In here we can see one of the aspects of machine-human relationship phenomenon.

Simulation

The digital factory approaches are based on simulation technologies, which enables experiments and validation on various manufacturing system patterns, processes, and products. An example we can find in the pharma industry is the use of digital twin systems which enables the manufacturer to see the outcomes of the inputs they are using.

Simulation was known for a long time in the training and even in the risk reduction operations, it allows the human factor to run the simulation more than one time to size and capture the best practices to develop a scenario-based learning. The empowering technology allows manufacturing to have better resources use and reducing costs.

So, in fact, the use of simulation is based on real time inputs and parameters, and it is such a powerful tool that decision makers can use it to reach their aim or optimize production. Also. combining the use of CC, BD, Augmented reality, and AI can reflect many enhanced scenarios that can surely improve production (Lachenmaier et al., 2017). Simulation is also used in maintenance. The operator can run a simulation using the AR to perform tasks and then reduce the faults of both operator and the system together (Hořejší, 2015; Ong et al., 2020).

Industry 4.0 emphasizes simulation because it enables businesses to develop digital representations of their physical systems and procedures. Without altering the physical system itself, these digital replicas can be utilized to simulate various scenarios and enhance the system's performance. As well as lowering the likelihood of mistakes and downtime; this can result in significant cost savings.

Several industries, including manufacturing, logistics, and healthcare, can benefit from simulation. For instance, in manufacturing, simulation can be used to test various assembly techniques, optimize the architecture of a production line, and assess the effects of production process modifications. One of the main advantages of simulation is that it enables businesses to test and improve their systems and procedures in a virtual setting before putting those changes into practice in the real world. This lowers the possibility of errors and downtime and can assist businesses in spotting and resolving possible problems before they arise. Additionally, training staff members on new procedures and systems can be done through simulation, which increases productivity and lowers the possibility of human error.

New technologies and techniques are constantly being created in the field of simulation. The development of virtual reality and augmented reality simulations that enable users to interact with simulated systems in a more natural and immersive way, as well as the use of machine learning and artificial intelligence to create more accurate and sophisticated simulations, are some of the major trends in simulation today.

A virtual representation of a real-world system or process can be created using a variety of tools and techniques called simulation technology. Key technologies in simulation include the following:

Objects, systems, or processes that are being emulated are created as 3D models using computer-aided design (CAD) software. These models are employed in virtual environments to mimic the behavior of real items.

Finite Element Analysis (FEA) is a computational technique for decomposing a large engineering problem into smaller, more manageable components, each of which is then examined separately. FEA is frequently used to simulate fluid dynamics and structural mechanics.

Computational Fluid Dynamics (CFD): CFD is a technology that is used to model heat transfer, fluid flow, and other related processes. It is frequently used in the simulation of water and air flows in a variety of fields, including environmental engineering, automotive, and aerospace.

Using discrete, sequential events to simulate complex systems is a modeling technique known as discrete event simulation (DES). Logistics, supply chain management, and manufacturing are three industries that frequently employ this technology.

ABM, or *agent-based modeling*, is a simulation technique used to simulate large systems with several independent agents. Economics, ecology, and social sciences all frequently use ABM.

Various simulation techniques are utilized in the pharmaceutical sector to enhance production methods and product quality. Here are a few instances:

Process simulation: This entails modeling the production processes to increase productivity, decrease waste, and guarantee product quality. Process simulation can be used to pinpoint possible bottlenecks, forecast the consequences of manufacturing process modifications, and optimize parameters to increase output and decrease waste.

Scale-up simulation: Before moving on to larger-scale production when developing a novel medicine, researchers frequently do small-scale laboratory tests. Predicting how a manufacturing process will behave when scaled up from the laboratory to production scale is known as scale-up simulation. In order to reduce the chance of failure, this can assist detect potential problems early in the development phase and optimize the scale-up process.

Simulations for quality control can also be used to foretell a product's quality before it is produced. It is feasible to forecast the quality of the finished product and find potential problems that could affect product quality by modeling the chemical and physical properties of the product and simulating the manufacturing process.

Simulation with virtual reality (VR) and augmented reality (AR): The pharmaceutical business is using VR and AR technology more and more for training and simulation. Healthcare personnel can be trained using VR, for instance, to replicate complex procedures like surgery in a secure setting. In order to provide real-time guidance and feedback during manufacturing operations, augmented reality (AR) can be utilized to overlay digital information onto the surrounding environment.

Augmented reality:

AR or VR are the names of Augmented reality. It is the technology we can see in the games and movies industry. In fact, a person can wear a certain type of goggles that reflect the experience of 3D imaging. AR technology has improved overtime. Some authors see AR as challenge more that an opportunity in routine operations (Syberfeldt et al., 2017). But AR is an operator enabling technology, providing imagery data to the operator, reflected to him in a 3D projection to perform the task. It can be used in two approaches: in the maintenance or in the assembly tasks. The two different approaches can happen in simulation, when the operator has the experience in performing the task in the 3D imaging using AR, and in using the AR as assistance during the process of the given task (Hořejší, 2015). In manufacturing, this can help not only handling the lack of experience of the operator but also providing a better result. However, using AR technologies can be the solutions in upskilling the human factor to meet the requirements of Industry 4.0 (Hořejší, 2015; Wagner & Schmalstieg, 2009). In terms of operator 4.0, we can see a type of operator called Augmented operator according to (Fantini et al., 2020). The operator aided with an AR application can, not only, perform the task better and have a better experience but also the AR technology enables the operator to have a better-quality result when it comes to quality control and assurance. Using AR technology requires imagery as mentioned. Using the imagery and 3D imagery solutions enables the use of the types of optics as follows (Alcácer & Cruz-Machado, 2019; Syberfeldt et al., 2017).

- Video – amalgamated worlds (real and virtual) into the same digital view.
- Optical – real world with virtual objects overlaid directly on the view.
- Retinal – direct projection of virtual objects onto the retina with the use of low-power laser light.
- Hologram – real world mix with virtual objects using a photo- metric emulsion.
- Projection – projection of virtual objects directly on real-world objects with the use of a digital projector.

AR helps in maintenance, quality control, defects detection and preforming tasks in general. This all can also make a difference in decision making moments not only in the top management levels but also in the lower management. All of this can be reflected on the key performance indicators (KPI's) of the operates.

Additive manufacturing:

3D printing is one other name to define this concept which is considered as the next step in the Industry 4.0 emerging technologies. Some see its high costs as a barrier when the topic comes to discussion. The cost can differ from hardware to software subscription using AI aided designs or workforce training. But many others see it as the chance of creating better products. In a world where the consumer behavior is constantly changing, 3D printing is the response to design the needs of the consumers. Also, the benefit of using 3D is time reduced models' creation which we can see in the automobile industry (Kim et al., 2018). In order to define this concept, one can say that three-dimensional objects are created by using layer by layer three-dimensional printing (3DP), also known as additive manufacturing, using a computer-aided design (CAD) model. In other industries and ear of research like the health care systems they have started to use not just 3D printed drugs, but also in some cases there are prototyping printing of human bones replica.(Bozkurt & Karayel, 2021).

Discussing 3D printing is a huge topic which includes the analysis of the materials that are needed to print the prototype. These materials can be costly even on smaller scales, which can highly raise prices. Another challenge is the energy consumption of using these technologies (Chang et al., 2018). In the last part, prototyping using layer by layer printing can help in many ways to create the desired object which can help people with less hand skills. Also, in this technology, by using IoT with the help of Machine Learning, we can have better results in each time preforming the printing. But 3D printing can't yet help in mass production, once this technology needs much more time to produce one object. Again, the use of CC with the power of AI can reflect a better experience in the layer-by-layer printing (Elbadawi, McCoubrey, et al., 2021).

Horizontal and vertical integration systems:

The use of technologies of Industry 4.0 needs to happen at an integration level. Designing, engineering, production, marketing, logistics, and supply chain operations, everything must have an integration scenario to allow the systems to have a better data flow to reach a better quality. This information flow among the system applications on the different levels of automation can have two different types of integration: vertical and horizontal. In real-time, data sharing is enabled by these two kinds of integration (Suri et al., 2017). Horizontal integration involves intercompany integration, developing an interconnected ecosystem within the same value creation network; it is the basis for close and high-level collaboration between several organizations (Shariatzadeh et al., 2016). To accomplish interoperability on the development of these systems, based on industrial standards, and enabling the interchange of data or information, an independent platform is required (Liao et al., 2017). Vertical integration is a networked manufacturing system, the intra-company integration, and is the foundation for exchanging information and collaboration among the different levels of the enterprise's hierarchy such as corporate planning, production scheduling or management (German, 2015; Zhou et al., 2015). Vertical integration ‘‘digitizes” all the process within entire organization, considering all data from the manufacturing processes: quality management, process efficiency or operations planning that are available on real-time. By this, in a high level and flexible way, providing the small lot sizes production and customized products, the vertical integration enables the transformation to smart factory (Gilchrist, 2016; Shariatzadeh et al., 2016). It's important to mention that standards must be the basis of the vertical integration. Vertical integration is the basis for communication and cooperation among the various levels of the enterprise's hierarchy. It is a networked manufacturing system, intracompany integration, and a networked manufacturing system (Shariatzadeh et al., 2016). Vertical integration "digitizes" all business operations by considering all real-time data from manufacturing processes. This allows the vertical integration to enable the transformation to higher level and more flexible manner, providing the manufacturing of small lot sizes and customized products. It's crucial to note that standards must serve as the foundation for vertical integration (Liao et al., 2017).

According to several authors (Landherr et al., 2016; Lee et al., 2015; Liao et al., 2017), I4.0 paradigm uses both systems of integration, on all levels and phases of the manufacturing. System integrations needs real time data that offer each element of the system to have real time reflections. This itself is key, enabling technology that relies on IoT of the sensors which provide data, in some cases CC and BD are involved in the system in the case of outsourcing. The integration of one system can have an agile approach to manage the resources as well the outcomes. Using agile approaches in the system integration can reflect the old-time management of Kan Ban methods which we can see that has better outcomes in the field of project management, allowing all the participants in the system to receive and send feedback that can for sure improve the quality of a service or a product and even results in better experience for the operators and the consumers (Abdi Khalife et al., 2020).

Autonomous Robots

On all the technologies of Industry 4.0 the study has focused on mentioning the ability to have better out comes using the machine learning of AI which can reflect the name *autonomous robots*, a name that comes from the idea of a robot that acts and performs tasks without human intervention in the system. Not just that but autonomous robots can collect data using IoT and the integration systems to result in better outcome. It is also the ability of solving much more numerical problems without the need of the human to watch and observe (Alcácer & Cruz-Machado, 2019). If we can choose one element of the Industry 4.0 to be the head of the pyramid, it is the autonomous robots. They combine not only the use of IoT, CC, BD and 3D printing but also are integrated into the system in both types of integration and, on top of that, they use CPS, which makes it the core of the fully automated factories. Using AI application in robots can be seen in manufacturing and in other applications (Zakhama et al., 2019). One of the greatest benefits of using such systems is avoiding human operators to deal with hazards in the workplace or in places with high risk. This is noticed in the study that uses robots in the painting and the grit blasting in the industrial level. Also using these technologies can reflect better results than human force in terms of quality in the automobile industry using Electrostatic coating methods for better insulation practices.

In regards of AI, this thesis has taken into consideration skills and competencies which are related to I4.0, also known as the skills of Operator 4.0, the worker who can operate these technologies. Later, it will become important to consider that there are a set of skills that require the human workforce, which make them the center of this Industry. But regarding the essential skills, it is noticeable that coding skills is considered the most important. Moreover, we can see that the analytical skills are also important. In fact, now we can use AI applications found online as an open source to write a code and run a program, which means that many jobs can replaced by AI applications. It is part of the interest of this thesis, as follows a human centric approach, to discuss how much this will affect the human jobs. There are many open AI applications which can perform design jobs, coding, and even academic writing. One can find examples of Open AI if search on Google or by using any search engine. It is necessary to mention, though, that even the Open AI applications require skills to conduct tasks using AI. It is necessary to provide good wording, a clean code, and keep the tasks required to the AI clear. Each word typing can make a difference. But still the question is: if these are the open AI, what are the capabilities of the application which requires subscription.

Cybersecurity (CS)

The new term of information high level security protecting, detecting, and responding to attacks in the cyber space. Attack means affecting any part of the system by some person who has no permissions of access to a certain system (Trust, 2019). CS is the most challenging part of adopting Industry 4.0 applications in the manufacturing or even in any applications that involve connection to the cyber space. The first thing that pops-up when speaking about cyber-attacks on the system is the IoT (He et al., 2016). One can search on Google or any other online search engine about cyber-attacks map of the world and then we can see how much cyber-attacks can jeopardize any system, and we can see how many cyber-attacks are happening in each second. But, still, the inventors of IoT based and assisted systems assure the safety and the security in that system. However, using automated systems can have less costs in using than the technologies of BD and CC; as mentioned in the BD & CC section above. However, this means that the system is not closed anymore in the face of many hackers who are known by the great skills they have. Hackers are always looking for a weak point to penetrate the system and in manufacturing we can see three main weaknesses that they can penetrate the system from.

Most of the manufacturing devices can be running for weeks and months leaving them without security updates, and this can be one of the reasons. The other two reasons are related to the use of CC where, in many cases, the company doesn't defect an old user's access to the system or provide multiple access points or pathways, permitting the attackers to find a point where they can enter and damage the system from. One important thing is that cyberattacks could be of internal and/or external sources in the organization. In smart manufacturing, investing in CS can be the most important investment in the system. Because the risk of a cyber-attack will not only jeopardize the system of manufacturing but rather the whole integrated system. A part of the integrated system is the consumer and in some industries, for example the pharma industry or even the automotive industry, any breach may lead to health and safety risks on the consumer. also, CS is the most challenging part in this industry which is a huge obstacle facing SMEs (He et al., 2016; Kannus & Ilvonen, 2018). intaking into consideration the latest open AI applications, there are many of them that, using photos from the users, develop a whole new image. These applications became popular in 2022, but if we take a closer look at the privacy policy, which is one of the requirements to get their access, the user is informed that these applications own you face print after using it. However, it is very concerning that people are always just pressing accept on the privacy policy or the cookies settings, which can lead to invading the privacy of the users. Yet, some countries, like EU countries, show some concern about these issues by discussing the General Data Protection Regulation (GDPR) but still the awareness is quite low in these regards.

Cyber-Physical Systems (CPS)

Cyber-physical systems (CPS) can be viewed as an innovative technology that permits control by integrating physical and computational environments of interconnected systems. CPS is the merger of ‘‘cyber” as electric and electronic systems with ‘‘physical” things. The ‘‘cyber component” allows the ‘‘physical component” (such as mechanical systems) to interact with the physical world by creating a virtual copy of it (Lee et al., 2015; Monostori, 2014b). So how is that different from the Autonomous robots? Both technologies depend on the IoT and the provided data but still CPS is an interacting part physically in the system. This CPS can be a part of human aided operation of full automated system. When we mix the concept of industry 4.0 with the concepts of smart factory, we always involve the CPS (Lee et al., 2015; Romero et al., 2016).

In a simple way we can elaborate the definition of this system as follows: it operates using the physical data from the sensors in the different types of the sensors. Using the data from different sensors in the system means the use of IoT to exchange the data. Then again physically the system checks the requirements it needs to produce the required output. In such a study aimed more to the decision makers rather than technical person, the use of CPS is the concept of using the technology of Modicon 084 mentioned in the introduction. But with the help of IoT. so, to conclude this Industry 4.0 emerging technologies can be found not only in manufacturing but also on the personal level in many products of smart home and cars and even smart watches (Bagheri et al., 2015).

Blockchain

In reviewing many documents about the Fourth Industrial Revolution, one can’t help but to notice differences between authors, which can be reflected on their domain. There are ten mostly known I 4.0 technologies in the world, while some other not less important technologies are not included within this selection. One of them is the Blockchain technology; it plays a major role in the development of the technologies. (Cerika & Maksumic, 2017; Liao et al., 2017; Suri et al., 2017). A series of blocks called a blockchain can be thought of as a public ledger where all committed transactions are kept. When more blocks are added to it, this chain keeps expanding. The key features of the blockchain technology include decentralization, persistence, anonymity, and auditability. By combining many key technologies, including cryptographic hash, digital signature (based on asymmetric cryptography), and distributed consensus mechanism, blockchain may operate in a decentralized environment. Blockchain technology allows the decentralized processing of transactions. Blockchain can therefore significantly reduce costs and increase efficiency.

It is worth to take this technology into consideration in studies regarding Industry 4.0 not only because of the NFT non fungible tokens part of this technology, which will be discussed in the pharma industry analysis. Blockchain technology was released in 2008, when there was no real confirmation of who had invented Bitcoin, which is the most well-known cryptocurrency. Its creation is attributed to Satoshi Nakamoto. As mentioned, NFT is a part of this technology which now plays a good part in the customer loyalty (Chiacchio et al., 2022).

Blockchain technology has the potential to completely transform several industries, including the pharmaceutical sector. Blockchain presents a promising option for tackling several issues encountered by the pharmaceutical business, such as supply chain inefficiencies, counterfeit medications, and regulatory compliance because of its decentralized and immutable nature.

One of the most significant applications of blockchain in the pharma industry is in the supply chain. The current pharmaceutical supply chain is complex, with multiple intermediaries involved, making it vulnerable to fraud, counterfeiting, and diversion. Blockchain can be used to create an auditable and tamper-proof record of every transaction in the supply chain, making it easier to track drugs from the manufacturer to the end consumer. This can help to prevent the distribution of counterfeit drugs and ensure that drugs are stored and transported in optimal conditions.

Clinical trials are another area in which blockchain can be applied in the pharmaceutical sector. Drug development must include clinical trials, but these studies are frequently time-consuming, expensive, and vulnerable to data manipulation. Researchers may build an unchangeable record of every study, including patient information, trial protocols, and results, by using blockchain technology. This can promote transparency and assist maintain the validity of clinical trials. Blockchain can also be utilized in the pharmaceutical business to ensure regulatory compliance.

Good Manufacturing Practices (GMP), Good Clinical Practices (GCP), and Good Pharmacovigilance Practices (GVP) are just a few of the laws and standards that pharmaceutical businesses must abide by. Pharmaceutical businesses can develop a safe and open system that monitors compliance with these rules by utilizing blockchain technology. This can aid in lowering the possibility of non-compliance and the related consequences.

Operator 4.0

With the development of the industry the requirement to develop the human power that is part of it became essential. As it was mentioned in the introduction of this chapter, human power had to adjust to each stage or period of each industrial revolution. Moreover, Industry 1.0 required the human power to perform conducting manual work; while Industry 2.0 required the ability, skills and competencies of using hand tools and computer Numerical Control (CNC) of machine tools. At the time of the Third Industrial Revolution, the operators were required to be involved in cooperative work with robots and computer tools, also known as human-robot collaboration. But in Industry 4.0 the case was with the concept of operator 4.0 (Longo et al., 2017; Ruppert et al., 2018; Scheffer et al., 2021). Operators 4.0 can be defined with the set of skills and competencies which enables them to be aided by the systems of Industry 4.0. And this thesis has related all the aided technologies with the different operators underlaying operator 4.0 concept. The following are types of Operators 4.0 (Fantini et al., 2020):

- an analytical operator uses the real time analytics of BD.
- Augmented operator and Virtual operator.
- a collaborative operator uses collaborative robots to work side by side to complete, non-ergonomic activities.
- a healthy operator is a worker who wears real time health data provided from sensors.
- a smarter operator uses the help of AI conducting tasks.
- a social operator focuses on the use of mobile and social collaborative methods to connect smart operators on the shopfloor with smart factory resources
- a super-strength operator uses lightweight and flexible biomechanical systems.

Thus, the training of the operator 4.0 is something expensive and even considered as one of the obstacles of adopting Industry 4.0 (Longo et al., 2017; Scheffer et al., 2021).. Therefore, what are the skills that an operator needs to conduct tasks in the Industry 4.0 environment? This discussion also involves how operator 4.0 can tackle the failure of system, in cases in which will be necessary to go back to the old manufacturing methods. All of this has been researched and will be covered in the next sub chapter.

2.2 Industry 4.0 skills and competencies

Considering this study human centric, it is necessary to think about what are the skills that the Operator 4.0 needs to have to be the center of I4.0. By saying Operator 4.0, this part of the text needs a different approach than the previously mentioned one. Operator 4.0 is the human being who can control some or all the applications of Industry 4.0 in the different areas of economy.

To gather the aimed data, Scopus database was analyzed based on the following search Skills and competencies required by Industry 4.0: (((“human factor”) OR (“operator”) OR (“smart operator”) OR (“workforce”) OR (operator 4.0)) AND ((“Industry 4.0”) OR (“4th industrial revolution”) OR (“smart factories”) AND (“training”) OR (“education”)) AND ((“skill*”) OR (“Competenc*”)).

Running the search on the Scopus database, 588 documents were found, covering the years of 2015–2021 in all the fields, except for those mentioned in the exclusion criteria. Then, their number was decreased to 266 using the condition of exclusion (three citations at least per document). The search was done in January 2022. After that, using VOS viewer software, the citation analysis of the documents was conducted to determine the top cited articles in the given topic and to create a map depicting how much they are connected by the citation links of the documents and authors. Then, the articles were examined to help creating an image of what are the most suitable skills that can be built through training to reach the efficiency of the competencies in the workplace to cooperate with Industry 4.0. After the analysis, the top 20 articles were used to reach for the following.

An important thing should be considered as justification of using such methods. Talking about advanced technologies is somehow silly without the real use of those technologies in conducting the research which has resulted in this thesis. The technologies used in this thesis used AI to find the most related and top cited documents in terms of not only I4.0 skills and competencies but rather the whole literature review of the study as well. Using the cloud computing on public domains with other authors brought much more richness to what to be included or not (while choosing the documents, including and exclusion criteria which was used as method). And of course, using the Big Data was part of reaching to the full text of the documents found during the bibliometric analysis. 37his was the motive behind using these complex ways of reaching, seizing, and analyzing the data of the research. Therefore, here are the main results of the skills and competencies article. It is no doubt that humans as the center of this industry are the key to the success of Industry 4.0. Thus, Operator 4.0 has a minimum requirement of the skills that those studies discussed (Blayone & VanOostveen, 2021; Caputo et al., 2019; Fantini et al., 2020; Hecklau et al., 2016; Jerman et al., 2020; Kadir & Broberg, 2021; Kipper et al., 2021; Papetti et al., 2021; Ruppert et al., 2018; Whysall et al., 2019), and they all agreed on a similar model which can be found clearly in (Hecklau et al., 2016), which has divided the skills to four main categories. The four groups of skills are:

- Personal competencies (flexibility, ambiguity tolerance, motivation to learn, ability to work under pressure, sustainable mindset),

- Social/Interpersonal (intercultural skills, language skills, communication skills, networking skills, teamwork, ability to transfer knowledge, leadership skills),

- Technical (technical skills, media skills, coding skills),

- Methodological (creativity, research skills, problem-solving, conflict solving, decision making).

In the study database we can see that there are some studies proposed more than 4 skill and competencies categories in their skills models, but this study focused on the mentioned above. Those studies which include more than 4 sets of skills have proposed different ways to upskill the workforce to meet the requirements of I4.0

Scenario-based learning (SBL), education 4.0, and vocational training are believed to be the most suitable to match the required skills compared to academic degrees (Dworschak et al., 2014; Erol et al., 2016; Subekti et al., 2019) . A study, besides the ones which have used the text mining techniques (Fareri et al., 2020; Pejic-Bach et al., 2020), resulted in comparing most of the models resulting in a "Five dimensions of worker readiness competencies model" (Blayone & VanOostveen, 2021) discussing most of the studies which have proposed other models of competencies to meet the requirements of Industry 4.0 (Abbasi et al., 2013; Adolph et al., 2014; Blayone & VanOostveen, 2021; Dworschak et al., 2014; Erol et al., 2016; Fareri et al., 2018; Hecklau et al., 2016; Jerman et al., 2020; Mourtzis, 2018; Pejic-Bach et al., 2020; Razali, 2018). And all those studies agreed on the used model of this thesis with minor difference about the personal skills where some of those studies named it interpersonal skills. Thus, other studies' models have focused on the skills needed to enhance the machine-human relationship (Jerman et al., 2020). The need for new behaviors in the machine-human relationship is important and it is challenging at the same time; for example, the trust in the machine, the system, and the connectivity, again, can be challenging in the era of Cybersecurity and the communication infrastructure as well. Also, this part of the thesis is an attempt on highlighting the importance of using programing and coding skills. In the end, many studies highlighted how much it is important to have decision-making skills, as it appears in most of the studies as a soft skill, while other studies find it more related to AI systems. The question remains on what is the most important skill to have: programming or decision making? This part of the study concluded that, even though both are indeed needed, decision making can be more accurate and effective with the use of machine learning (ML), as one of the AI applications. But decision making and coding skills should be combined because of ML. It needs to be able to work with cloud systems and big data, both of which require programming languages. This thesis hasn't mentioned anything related to programming so far, the needed programming languages based on a study has been made on the LinkedIn database that C, C++, assembly, and JavaScript are in use in I4.0 applications (Pejic-Bach et al., 2020) (Landherr et al., 2016). Examining (Hecklau et al., 2016) connected to the most crucial citations for the definitions of Industry 4.0 as well as (Alcácer & Cruz-Machado, 2019) which led this thesis to elaborate the definitions of Industry 4.0, another finding is that the citation score could be related to the name of the author and the connections between the authors rather than the in-depth information of the document. A further result is that most of the highly cited documents are not in impact factor journals. It is probably because non-IF journals are used in a larger circle than the journals with impact factor. The theory of the study that claims the Covid-19 crisis accelerated and increased the dependency on IT-related systems and Industry 4.0 emerging technologies is somehow supported by the fact that this crisis has opened our eyes to the ability of those technologies as crisis response and contingency plans as those studies have discussed before (Nickinson et al., 2020; Wang et al., 2020).

However, the remaining important issue and question is the education of the new coming generation. Is Education 4.0 in developed countries enough? And will the Operator 4.0 be able to control Industry 4.0 technologies according to the risk assessment of volatility, uncertainty, complexity, and ambiguity? Since the first industrial revolution the labor force must adjust to the requirements of the labor market. In each industrial revolution there were a new set of skills and competencies, which developed with their content; and the study which was published as part of this project, it has demonstrated several skills and competency models referring to the top-cited articles in the topic and more to new articles in 2020 that didn't have enough time to reach a high citation score. Thus, those models are comprehensive in that all the models have focused on the interpersonal skills and the technological skills. The most important skills and competencies are the interpersonal skills as many studies have confirmed that it is a must to be existed in the workforce on all levels (Abbasi et al., 2013; Adolph et al., 2020; Dworschak et al., 2014; Erol et al., 2016; Hassan & Ismail, 2018; Hecklau et al., 2016; Jerman et al., 2020; Mourtzis, 2018; Pejic-Bach et al., 2020). Interpersonal skills are important where it is the crucial element, so human can surpass the machine. Also this thesis focuses on the innovation competencies. These kinds of competencies can enhance the ability of the human to use the machine relationship to create and invent using the AI and ML to have the maximum from these applications, which will make place for the human workforce in the workplace (Whysall et al., 2019). Fewer studies have focused on the Technical and domain skills which are more important to be related to the programming language which is the way to communicate with the computer. It is presumable that in the upcoming ten years these competencies will be categorized in the communication skills considered as a language, not a technical skill. Moreover, interpersonal skills and programming competencies will be necessary in all job profiles in the future, and the technical and domain skills must be developed based on the job profile. The question here is what are the most important interpersonal skills? It can be found in the model of (Armstrong et al., 2019; Dworschak et al., 2014; Ismail et al., 2019). As an ending statement that industry 4.0 may take most of the job profiles in the manufacturing area and even in the construction industry by 2030, because many companies have promised that they will go for the full green polices. And the full usage of industry 4.0 technologies in their daily activities. But still it has created more job profiles that are even safer for the workforce and seek more comfort for the human and as always humans could manage the revolution in his/her sake learning what it needs to be controlled by. This leaves us with increased questions about the driving forces of these technologies, if we want to have a safe and real time application, on all levels, with which Internet of Services (IoS) is involved, we need the glue of communication in the age of I4.0, which can't be provided without the use of the fifth generation of communication.

Thus, humans will play a role of success in this transition; but still, there should be considered the question of the availability of material to produce the chipsets of the computers, for example. Besides, mankind has to face several other challenges (e.g. shortage of energy and water, climate change, different epidemics, economic crisis, digitalized world). In order to cope with and adjust to any faced challenges, it is extremely important for humans to see clearly what kind of new skills and competencies will be important in the future.

If we take a closer look on what AI applications have open access to the public, we can see that in 2021 and 2022, there are some open AI applications that can write program codes in less than a minute as well as there are some Open AI that can even conduct a research, as is the case of Jinne open AI and open AI chat. Here we can notice two things mainly: that coding skills are not the most important in terms of what are the essential skills, but, still, it is recommended to have a minimum percentage of skills human force in terms of coding and IT related skills. But the other issue or question asked in the study questions was about what skills can be valuable in the case of the system going down, not only to operate I4.0 emerging technologies but also to operate in no technologies existed? And the answer to this question was reached by interviewing the project managers of EU funded I4.0 project in Jordan later in this thesis. The main idea is to have the basic knowledge of the new eras of industrialization, which can be related to mathematics in terms of robotics, and analytical skills in terms of social and career pathway.

2.2.1 What is the case of skills and competencies in Jordan?

Skills and competencies are changing over time with each development. This can be seen above in the detailed skills and competencies section, in regards of Industry 4.0. However, in any labor market, in any state around the world, we can analyze cases of the required skills and competencies using the method of text mining of the job advertisements which we can see in these two articles, that gave a good example of reaching the required skills and competencies which we can see below mentioned and as well agrees on the previous part of skills model (Fareri et al., 2020; Pejic-Bach et al., 2020). In the case of Jordan, we can see that the unemployment rate is higher than 30% in total and around 50% in the youth among the country. In most of the studies conducted using text mining, the jobs database or platform used was LinkedIn as a source for job advertisements. LinkedIn was chosen because it is the leader in publishing job advertisements covering a broad range of organizations, countries, and job types as we can see in this document (Bradbury, 2011). Therefore, more or less 1500 advertisements can be found about all the vacancies available in Jordan. For the same search in Hungary, we can see that there are around 16,000 vacancies available in the Hungarian labor market. This search was conducted during November 2021 and the same results for a similar search can be seen in 2022. Hungary was chosen as an example because it has the same population and geo spatial area as Jordan. Text mining techniques were a limitation to this study because it is difficult to apply them into the job searches in Jordan. However, in terms of Industry 4.0, a previous study have summarized the needed job profiles most related to I4.0 manufacturing (Pejic-Bach et al., 2020).

- Supply chain analyst (17)
- Supply chain engineer (3)
- Cyber-physical systems (CPS) and the Internet of things (IoT) for a robotized production engineer (No match)
- Digital manufacturing engineer (2)
- Smart product design (2)
- ICT specialist for factory automation (3)
- Customer satisfaction manager (132)
- Enterprise software specialist (234)

Conducting one search at a time for each job profile which is known since 2018, those are the most related to Industry 4.0 in Jordan. We can see the results by looking at each number next to each job profile above. Knowing that those results represent all levels of experience, home office or at workplace.

On the other hand, if we look at the reports of departments of statistics, we can see that the ICT reports, last updated in 2016, show a work force in government related to IT of 27,127 people, which represents around 3.5% of the total workforce in the government or public sector. Having a look at the same reports we can see that there are tables about the current employees, the actual and future needs of the information technology discipline by economic activity and specialization in 2016. Here it is possible to find, in table number 3, the numbers of future employment needed in the IT sector, yet these reports are late updated 2016.

Table 3 No. of Current Employees, the Actual and Future needs of the information Technology Disciplines by Economic Activity and Specialization 2016

Industry	Future Needs of Employees with IT Specializations		Actual Needs of Employees with IT Specializations		Number of Current Employees with IT Specializations	
Manufacturing	Female	Male	Female	Male	Female	Male
Computer science	90	512	99	717	322	2206
Computer information system	42	295	44	395	92	1127
Software engineer	0	56	15	149	55	373
Computer engineer	11	39	8	32	29	244
Communication engineer	16	76	11	75	48	186
Electronic engineering	0	0	2	0	12	17
Business and E-commerce	0	0	0	0	3	11
Management Information Systems	3	3	3	3	3	3
Computer and Network Engineering	8	17	11	23	30	77
Communications and Software Engineering	2	10	2	10	2	16
Information & Communications Technology (ICT)	0	0	0	0	2	18
Electronics Engineering	7	7	5	6	12	50
Communications and Computer Networks Engineering	1	1	0	0	5	22
Internet Technology	0	0	0	0	8	17
Computer Networks	0	0	0	0	0	0
Education and E-Learning Technology	0	5	0	19	11	31
Computer Systems for Multimedia	0	0	0	0	0	2
Computer and Communication Engineering	0	0	0	0	0	0
Information Computer Technology / Communication	0	0	0	0	13	2
Applied Software	0	5	0	5	0	8

Source (Department of Statistics/ Information Technology and Communications use in Economic Establishments Survey 2016)

In the same reports we can see that for each sector of the economy there are preferred universities to hire from in terms of IT services, here the thesis focuses on the manufacturing and IT because of the relation of IT and manufacturing into Industry 4.0 and in the government reports the pharma manufacturing is included in the manufacturing in general in Jordan. In the following table number 4 we can see what those universities are.

Table 4 Relative Importance of the Preferred University to the Establishment in terms of the Graduates' Efficiency in the Disciplines of Information Technology and Communications by Economic Activity 2016

Economic Activity/ Manufacturing	Relative Importance	No. of Establishments
	100.0	472
Balqa Applied Univ	16.9	80
Alhashimiyah Univ.	14.4	68
Science & Technology Univ. of Jordan	21.6	102
Yarmouk Univ.	5.3	25
Jordan Univ.	34.5	163
Mouta Univ.	0.0	0
Al Albait Univ.	0.6	3
Alhussein Ibn Talal Univ.	0.6	3
Tafilah Technical Univ.	0.4	2
German Jordan Univ.	0.0	0
Prince Sumaya Univ. of Technology	5.1	24
Alzaitouna Private Univ.	0	0
Alzarqa Private Univ.	0	0
Petra Private Univ.	0	0
Applied Science Private Univ.	0	0
Alisra Private Univ.	0	0
Philadelphia Private Univ.	0.4	2
Amman Alahliya Private Univ.	0	0

Source (Department of Statistics/ Information Technology and Communications use in Economic Establishments Survey 2016)

As shown in table 4, Jordan university with a relative importance of 34.5 among 163 establishments is the most preferred to hire from because it is known by the long history of high quality education and training. Therefore, we can see that these universities with high evaluation and experts, according to the Industry 4.0, are the top institutions in terms of advanced training, and use of new technologies. But it is necessary to add that all these reports go back to 2016 which can't give a clear indication of training related to Industry 4.0 emerging technologies.

These two tables can lead to the fact that there is a lack of skilled workforce in terms of the IT sector which is the most related to Industry 4.0 emerging technologies. Also we can see that there is only one university (Jordan university) taking the biggest share of employment readiness. We can also see in these tables that more vocational training is needed to adopt I4.0 emerging technologies, Because I4.0 needs more hard skills especially in the terms of CPS and mechanical emerging which can be the jobs, that the AI can't replace humans in conducting these jobs. But still even with the replacement of humans, CPS are not yet able to perform self-maintenance and it needs a human technician.

2.3 Demographics of the Jordanian economy/ internet coverage in Jordan/ pharma Industry in Jordan

Jordan has a population of about 10.1 million people, with a median age of about 27 years. The majority of the population is of Arab descent, with small Palestinian, Iraqi, and Syrian minority communities. The population is predominantly Muslim, with a small Christian minority. The Jordanian economy is relatively small, with a GDP of about $37.5 billion in 2021 according to the statistical department of Jordan. The service sector is the largest contributor to the economy, followed by mining industry and agriculture world bank data of Jordan. The main industries in Jordan include textiles, pharmaceuticals, and tourism. The country is also a major exporter of phosphates and potash. Jordan has a highly educated population, with a literateness rate of about 95%. Education is free and compulsory for children between the ages of 6 and 15. However, unemployment is a major problem in Jordan, with rates hovering around 18%. This is particularly true for young people, with over 50% of those under the age of 30 unemployed. The standards of living in Jordan are relatively high compared to other countries in the region, but there are significant disparities between the rich and the poor among the community. The country has a large informal sector, with many people working in informal jobs or, as named by the Jordanian government, daily income. Income inequality is also a significant issue in Jordan, with the top 20% of households earning about 14 times more than the bottom 20% (Kamar & Selim, 2020). Jordanian economy had over history four unusual stages or time sprints, the first one before the formation of the kingdom, in 1921; in the period between 1921 and 1975; from 1975 to 1999; and from 2000 to 2022. 300 B.C Jordan was under the rule of the great Arab Neptunian civilization which ruled the area from the east bank of the Jordan river and the whole area of east of the red sea, fact which archology can witness on due to the architecture that appears in the area until reaching Tabuk/KSA. During that period Jordan was the path of trade and had different stops of the winter and summer trade journey that used to happen between the Arabian Peninsula and the great Syria back then. Jordan had the chance to host the summer events of trade at the time. This trade path was there as well in the period of 600 D.C (Piro, 1998).

In the modern history, the British colonization movements came to the area and drew the borders of Jordan to the east bank of the river in 1921. Then, the tribe system was being controlled by the British army, who started the police force as well in the country and the taxation system in place. Between 1921 and 1951 the British government took the chance to manage Palestine and Jordan under the same government until the end of 1951. In 1948, came the first economic crisis that effected Jordan due to a war, when Jewish came to Palestine, known as the 1948 war. Then the British army moved 60% from the Palestinian population to Jordan after the death tragedy of King Abdullah, the First, in July 1951. In 1951, the domain of the administration of Jordan over both riverbanks came to an end. In 1946, the formation of the Hematite Kingdom of Jordan took place. After 1951, Jordan started to build infrastructure which was only a road map which was existed even before to cope with the migration that happened. This migration increased the population from 250,000 people to more than 450,000 people. In 1967, the growth of population made it to 1,265,680 people due to the events around the Second War in Palestine. After that period Amman, the new capital of Jordan, became the growth pole of the area, where people from all over Jordan came to the city along with the people who migrated from Palestine. Later, Amman became the trade center of Jordan, hosting all kind of activities of economic growth. In the latest century, the economic growth became more organized in the area hosting many different activities (Mryyan, 2014).

With the road map connecting the capital with the south of Jordan, Aqaba was located by the sea, nesting the marine along with the north of Jordan, connecting Syria and Iraq at the time. In the 1960, manufacturing activities started to take place in the capital. 1960 was also the year in which i the Jordan pharmaceutical manufacturing stated to grow. In 1962, the Chamber of Industry of Amman was established, to become the regulatory commission of all the sectors of industry. According to the reports of the Amman Chamber of Industry and the documents of the Government's Department of Statistics, the Jordanian economy depends on the following industries holding the biggest shared of the GDP in the recent years.

According to Amman chamber of industry, industry in Jordan have witnessed a growth of 4.7% in 2021 after the recovery of COVID-19 crisis achieving a 24.5% participation rate in Jordanian GDP. Also, manufacturing affected the growth of many other economic sectors (transportation, logistics, banking sector, insurance). Also, the manufacturing sector played a major role in the food security area, maintaining the supply chain management activities before and after the crisis of COVID-19. Also, the manufacturing industry in Jordan took 93% of the export and on top of the exports were fertilizers, pharmaceutical manufacturing, textile, food, and beverages. Those industries have employed around 249 thousand people, which is 12.5% of the employment rate in Jordan. Also, according to the Chamber of Industry of Amman, the manufacturing facilities were flowing according to the table below.

Table 5 manufacturing activities facilities number, employment rate, capital, exports and growth rate in Jordan 2021

Manufacturing activity	Facilities number	Growth rate	Employees number	Growth rate	Capital Jordanian dinar (million)	Growth rate	Exports	Growth rate
Construction	993	-2.6%	10,714	-0.9%	199.4	4.3%	141,1	44.1%
Plastic	420	2.7%	9,786	10,3%	88.7	-1.5%	195,2	4.3%
Mineral mining	71	4.4%	7,790	-16.1%	508.0	1%	1,452,4	47.9%
Food and beverages	1,531	4.4%	41,345	9.1%	502.6	1.7%	657,7	5.2%
Textile and leather	607	-5.9%	22,923	4.4%	76.3	-0.4%	451,9	11.2%
Wood and furniture	999	-3.2%	6,180	-2.1%	43.1	-9.4%	18,9	27.6%
Pharmaceutical	128	3.2%	8,975	2.7%	313.2	12.1%	602,8	-6.3%
Chemical	465	-6.1%	13,813	20.8%	742.7	0.4%	1,070,0	5.5%
Engineering	1,990	-4.6%	30,313	-4.8%	1,217.4	-3.0%	653,3	45.2%
Packaging	601	-7.1%	9,574	6.1%	129.0	-3.3%	218,5	7.1%
total	7,805	2.3%	161,413	3.3%	3,820.3	-0.2%	5,462	18.1%

Source (Amman Chamber of Industry annual reports 2014-2021)

According to the Competitive Industrial Performance index (CIP), from 2021, Jordan placed 75th in the general indicator ranking, between countries of the world. In terms of added value of industries Jordan rank was 24th on the world level. Also, Jordan ranked 54th in the quality of exports. By looking at *Table Number 3*, we can see that there are some negative indicators which are highlighted in red; this happens mainly because of two reasons. The first is the covid crisis, which affected not only Jordan but the whole world trade and manufacturing activities. The second reason was the energy bills that are increasing because of the geopolitical changes in the world, that effected the gas and oil industry domination.

Also, one remarkable thing is the total of employees that are reflected in the table as 161,413 where the actual total is around 249,000. The differences between the two numbers were due to social security register in the country's industry. Thus, during covid-19 crisis the social security commission tried to register employees in the social security, but there were too many people working illegally in the construction field. Also, this difference might have been caused by people who have been paid in daily rates, which were not included in the 249,000.

Manufacturing in Jordan:

In the Jourdain economy, the biggest share comes from the services sector, contributing around 66.7% of the GDP, and the second share comes from the manufacturing industry, with contributions of around 18.17% of the GDP; the agricultural sector contributed with 4.3%. The manufacturing sector in Jordan is an important economic sector that supports the Jordanian exchange rate by contributing with around 1.4 billion USD in taxes, according to the Chamber of Industry of Amman. The main manufacturing exports are garments and textiles, pharmaceutical products, jewelry, electrical appliances, machinery and equipment, furniture, chemicals, minerals, and plastic products. According to the 2019 report, *the Economy of Jordan*, conducted by the Chamber of Industry of Amman, the neighboring Arab nations account for 44% of the imports from the Jordanian market, followed by North America (28%), Asia (21%), the EU (3%), and other countries (3%). Based on the Economic Complexity Index (ECI) reports, Jordan reached rank of 87 among the world in terms of exporting. And during 2018 and 2019, the United States, Saudi Arabia, India, Sudan, and Iraq were the biggest export destinations. The most important reason why manufacturing is the second contribution of the GDP is the Foreign Direct Investment (FDI) policies that have created encouraging polices of free trade zones. In the free zones, which are more than 30 areas in Jordan, investors are allowed to produce products to be exported with only 5% income tax and 7% sales tax. Using these polices has attracted foreign investors to conduct their activities in Jordan. This has helped the government in the unemployment rate and in tax income for the government.

Internet in Jordan (services, providers, users, and coverage)

Telecommunication Regulatory Commission (TRC) is the responsible for regulating all types of communications methods in Jordan. This includes the radio frequencies, internet, landline, and mobile phone. Moreover, the commission has set new guidelines for IoT in the beginning of 2016. This authority sets the limitations of the frequencies based on the technical data sheets of each technology. Also, they publish white papers in regards of all those technologies. Thus, those laws and regulations are associated with two bodies of the Jordanian government: the *Ministry of Digital Economy and Entrepreneurship* and the *Telecommunications Regulatory Commission* (TRC). The reference for those two bodies, are three main documents and laws as the following:

- Telecommunications Law no. 13 of 1995.

- General Policy for the Information & Communications Technology and Postal Sectors for 2018.

- General Government Policy for Universal Service in the Telecommunications Sector.

According to TRC and Ministry of Digital Economy and Entrepreneurship, from reports of 2021, the number internet users in Jordan has reach 103.5% of 11.7 million inhabitants. The service providers were more than twenty companies but only three were included in this thesis, since they have the biggest shares of both users and coverage. Internet services in Jordan have been set up as service packages by TRC, based on the speed and the download capacity with different prices based on the user needs. Internet services categories were two main (wired and wireless) and those two include the following, according to the government reports on the available service:

Wire internet services:

- ADSL internet service, internet speed in this category starts from 128kb/s and up to 24mb/s, and it has a 24/24 connection. In this category the ministry and TRC set a price limit based on the packages.

- Digital Leased lines, in this service the ministry and TRC have mentioned that this service is the best for the industrial era of the country, where one of the regulated services in this category is the Fiber optics, or coper wire systems, which allow the user to have more internet speed and special coverage in the areas of industrial activity in Jordan, which happens in most of the cases far from the cities and the wireless coverage. Also, the same prices packages apply but they can differ based on the internet speed and amount of downloaded gigabytes for each month. According to the TRC and the Ministry of innovation, the speed in this category reaches up to 56kb/s, but in here we can see that the data of the TRC and statistical department of Jordan. The reports were made between 2016 and 2018; that means it is outdated. but now we can see that there are companies like Zain and Mada can serve a speed up to 1000mb/s in some geographical areas of Amman the capital, Irbid and Al-Balqa governate.

Wireless internet services:

- WiMAX: using the wireless modem, which can be connected to the computer, tablet or phone without the need of a wire connection like ADSL or fiberoptics, was the solutions for many of the geographical areas in the country. This type of connection has the advantages of high speed and the ability to move the modem in different geographical areas using the coverage towers of the providers.

- 3G/4G/LTE: this service was the solution for many people in the areas in the south of the country, where connection depends on the coverage tower and the user's device. The user device must be connected to one of the service providers and support one of the technologies mentioned, it has a good speed and good download ratio but the speed depends on the tower coverage which can be an issue to many users as this study will demonstrate later. This service also was affected by the user's overload. In many geographical areas in the country the users' numbers increased 200% because of the COVID-19 crisis in regards of the online schools and the home office contingency plans.

Many different internet technology services existed in Jordan already, as the satellite internet for example. But the above mentioned categories were set by TRC to define the main services., but if we take a look on the published report of TRC about the telecommunication market indicators in Jordan in 2021/2022, not all of the actual services can be found, even though this is the most up to date report. It still misses satellite internet, which is available in Jordan.

- Fixed line telephony services
- Mobile services
- Fixed broadband services

If we review the reports, we can see that there are three main Fixed broadband services as we can see in the following figure (5)

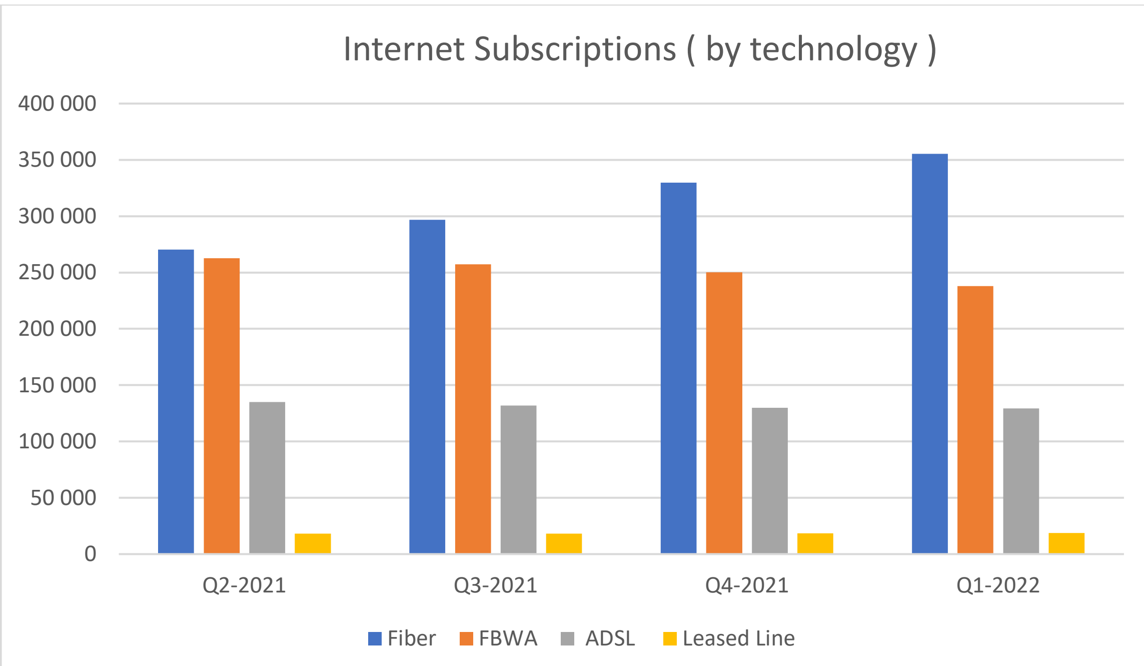


Figure 5 Subscriptions of the internet in jordan based on the technology type. Source (Statiscs deprtmnt of Jordan reports 2021/2022)

By looking at the figure we can see that in the last year fiber internet became much more in use in Jordan. Which is known as high-speed broadband internet connection that uses fiber optic cables to transmit data. It is more reliable and faster than traditional copper wire or coaxial cable internet connections. There are several companies in Jordan that offer fiber optic internet service to both residential and business customers. Some of the major providers of fiber optic internet in Jordan include:

- Orange Jordan: Orange Jordan is a telecommunications company that offers fiber optic internet service to both residential and business customers in Jordan. The company offers a range of fiber optic internet packages with different speeds and data allowances.
- Zain Jordan: Zain Jordan is a telecommunications company that offers fiber optic internet service to both residential and business customers in Jordan. The company offers a range of fiber optic internet packages with different speeds and data allowances.
- Umniah: Umniah is a telecommunications company that offers fiber optic internet service to both residential and business customers in Jordan. The company offers a range of fiber optic internet packages with different speeds and data allowances.
- Ooredoo: Ooredoo is a telecommunications company that offers fiber optic internet service to both residential and business customers in Jordan. The company offers a range of fiber optic internet packages with different speeds and data allowances.

Fiber optic internet is generally considered to be more expensive than other types of internet connections, but it is also faster and more reliable. If one is interested in getting fiber optic internet service in Jordan, it is recommended to compare the different packages and prices offered by the different providers to find the best option for their needs.

FBWA, or Fixed Broadband Wireless Access, is a type of wireless internet connection that provides high-speed broadband access to a fixed location, such as a home or office. It uses wireless technology, such as microwaves or millimeter waves, to transmit data between a wireless access point and a customer's device. FBWA is typically used to provide internet access in areas where it is difficult or not cost-effective to lay fiber optic cables or install other wired infrastructure.

FBWA internet is generally considered to be a good option for people living in rural or remote areas where other types of internet connections may not be available. It is also a good option for people who need a fast and reliable internet connection but does not want to pay for an expensive wired infrastructure. If one is interested in getting FBWA internet service in Jordan, it is recommended to compare the different packages and prices offered by the different providers to find the best option for your needs.

There are several companies in Jordan that offer FBWA internet service to both residential and business customers. Some of the major providers of FBWA internet in Jordan include:

- Jordan Telecom Group: this is a telecommunications company that offers FBWA internet service to both residential and business customers in Jordan. The company offers a range of FBWA internet packages with different speeds and data allowances.
- Umniah: Umniah is a telecommunications company that offers FBWA internet service to both residential and business customers in Jordan. The company offers a range of FBWA internet packages with different speeds and data allowances.
- Zain Jordan: Zain Jordan is a telecommunications company that offers FBWA internet service to both residential and business customers in Jordan. The company offers a range of FBWA internet packages with different speeds and data allowances.

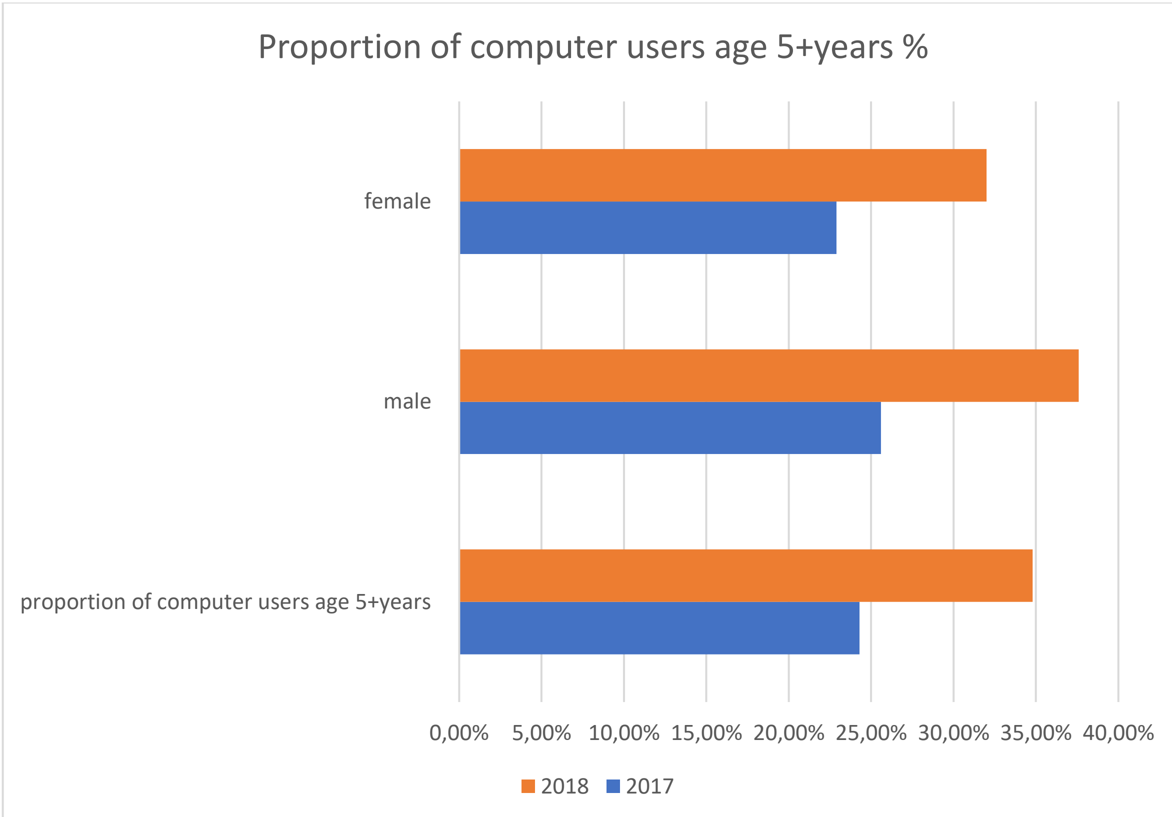


Figure 6 proportion of computer users age 5+years % in Jordan Socure (Statiscs deprtmnt of jordan reports 2017/2018)

**Please note that the percentages of the horizontal axis value are representing the Jordanian population.

It is difficult to estimate the exact number of computer users in Jordan, as there is no central source of this information after 2018. However, data from the International Telecommunication Union show that in 2020, 63.8% of individuals in Jordan were using the internet. This indicates that a significant portion of the population in Jordan likely owns or has access to computers or other devices with internet capabilities. One possible reason for the high rate of computer usage in Jordan is the country's strong education system and relatively high literacy rate. Many schools and universities in Jordan provide computer resources for students, and there are also several private and public computer training centers in the country. All these factors may contribute to the high rate of computer usage in Jordan. When people were asked in Jordan about what device they are using to log into the online and distance education classes during the COVID-19 crisis, most of the interviewed people said that they were using smart phones because it is relatively less expensive in terms of the device price and the internet charges, which was a challenge for students and families in Jordan.

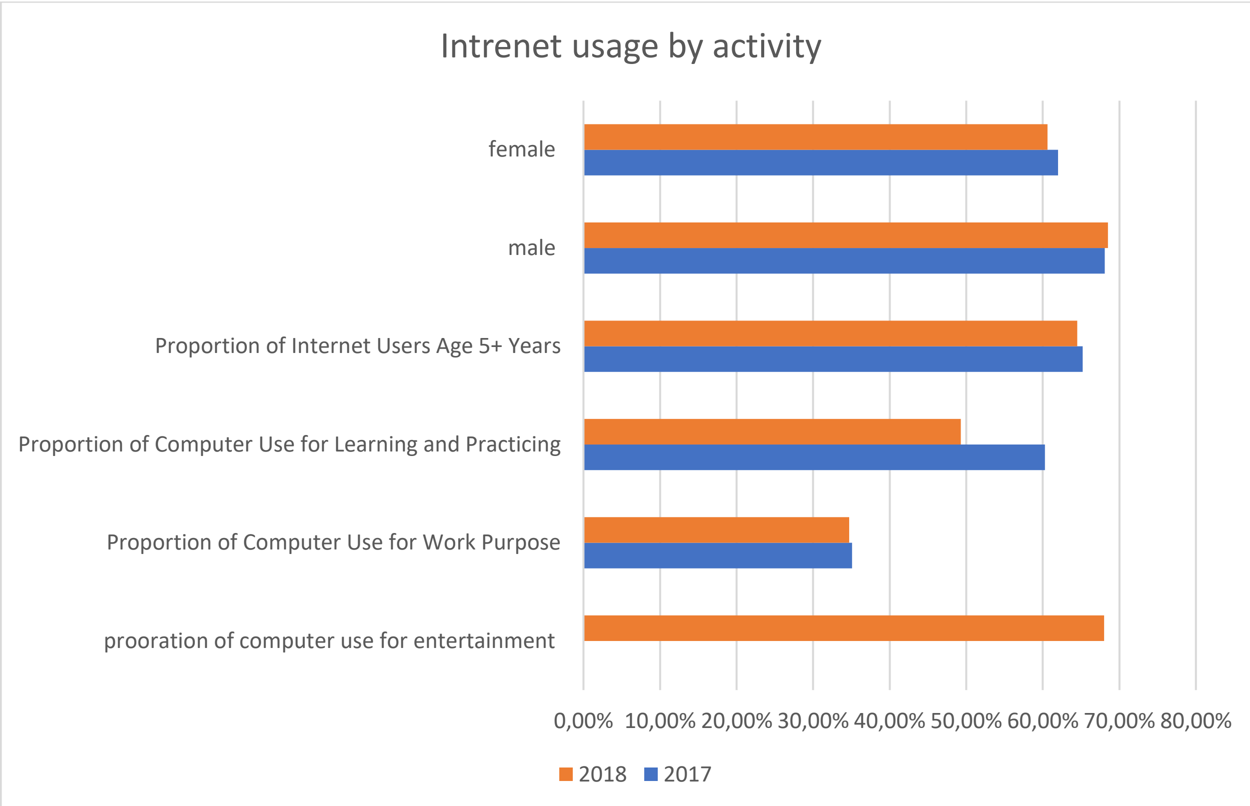


Figure 7 Internet usage by activity in Jordan scource (Statiscs deprtmnt of Jordan reports 2017/2018)

According to the International Telecommunication Union (ITU), the most popular activities among internet users in Jordan in 2020 were:

- Communication: This includes activities such as sending and receiving emails, using social media, and making voice or video calls.
- Information search: This includes activities such as using search engines, looking up news or information online, and using online maps.
- Online shopping: This includes activities such as purchasing goods or services online, using online banking or payment services, and booking travel arrangements online.

- Entertainment: This includes activities such as streaming music or video, playing online games, and using streaming platforms such as Netflix.

It is likely that these activities are also among the most popular among internet users in Jordan.

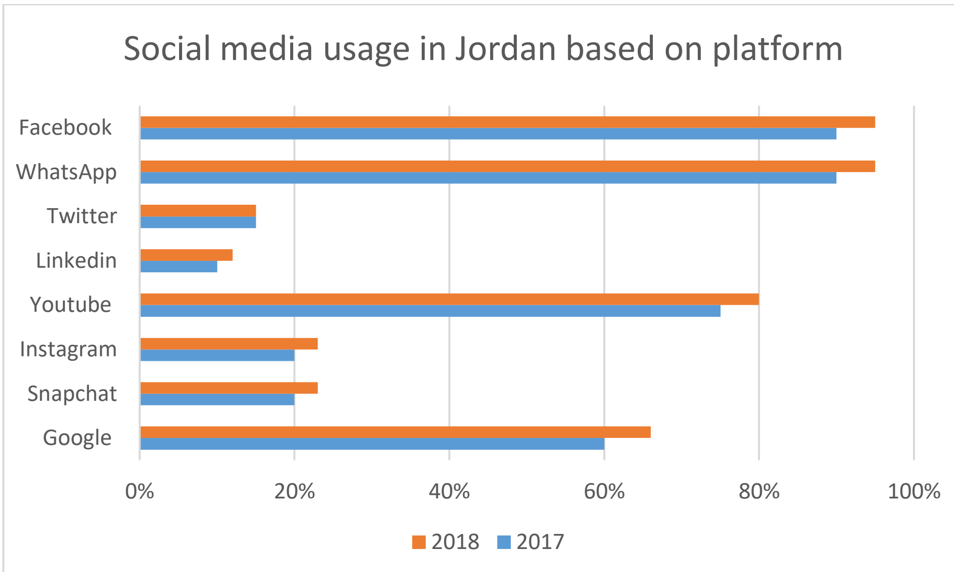
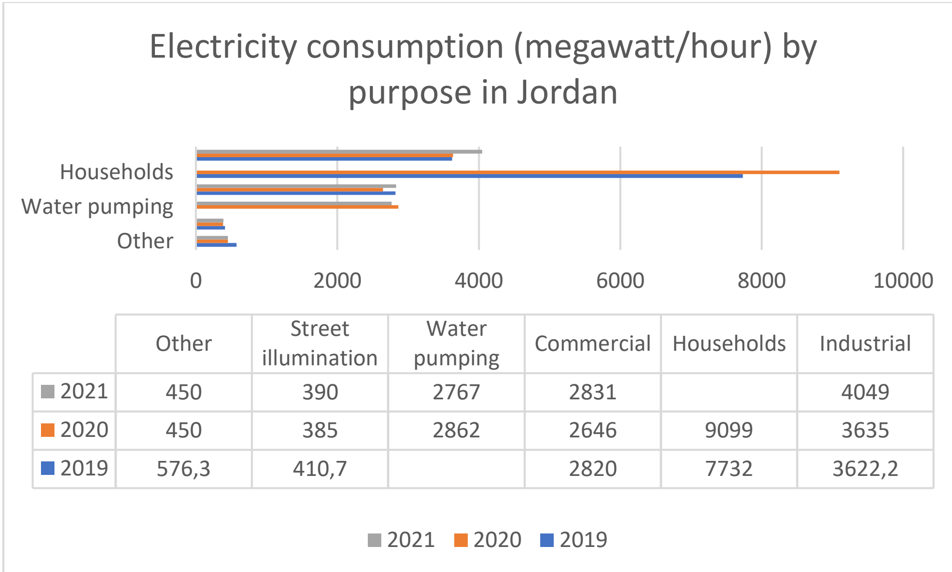


Figure 8 Socail meadia usge in Jordan scource (statiscs deprtmnt of jordan)

According to data from the International Telecommunication Union (ITU), the percentage of individuals in Jordan using social media was 70.9% in 2020. This suggests that a significant proportion of the population in Jordan uses social media platforms, such as Facebook, Instagram, Twitter, and LinkedIn. In addition to the ITU data, a survey conducted by the Arab Social Media Report in 2020 found that the most popular social media platform in Jordan was Facebook, followed by Instagram, Twitter, and LinkedIn. The survey also found that most social media users in Jordan were between the ages of 18 and 34, and that most users accessed social media via their smartphones.



	Other	Street illumination	Water pumping	Commercial	Households	Industrial
2021	450	390	2767	2831		4049
2020	450	385	2862	2646	9099	3635
2019	576,3	410,7		2820	7732	3622,2

Figure 9 Electrisity consumption (giga watt/hour) by purpose in Jordan source (statiscs department of jordan reports 2019-2022)

In this sense, electricity consumption is closely related to Industry 4.0, as the adoption of Industry 4.0 technologies can lead to an increase in electricity consumption. For example, the use of automation and IoT technologies in manufacturing can require the use of more electrical power for machines and sensors, and the use of cloud computing and data centers can also increase electricity consumption. On the other hand, Industry 4.0 technologies can also be used to improve energy efficiency in manufacturing. For example, the use of sensors and IoT technologies can allow manufacturers to monitor and optimize their energy use in real-time, and the use of advanced analytics can help manufacturers identify and eliminate energy waste. Overall, the relationship between electricity consumption and Industry 4.0 is complex, with both positive and negative impacts. While the adoption of Industry 4.0 technologies can lead to an increase in electricity consumption, it can also be used to improve energy efficiency and reduce overall energy use.

Internet coverage in Jordan

A set of internet services in Jordan is used by around the whole population in Jordan with rate of 103.5%. This percentage doesn't cover the geographic data, internet coverage or what this internet is being used for in the country. It was mentioned above that only three telecommunication service providers are discussed in this study, because they have the most coverage in the country. Regardless of the B2B internet services in Jordan, those are the main three service providers (companies).

- Umniah: a leading mobile operator and ISP that offers broadband, fiber, and wireless internet services. Umniah is a telecommunications company and internet service provider (ISP) based in Jordan. The company was founded in 2005 and is a leading provider of mobile, broadband, and fiber internet services in the country. Umniah is a subsidiary of the Bahraini telecommunications company Batelco and has a strong presence in the Middle East and North Africa region. The company offers a range of internet packages for both residential and business customers, with a focus on providing fast and reliable connectivity. In addition to its internet services, Umniah also offers a range of other telecommunications services, including mobile, fixed line, and TV.
- Zain: Zain Jordan is a telecommunications company and internet service provider (ISP) based in Jordan. The company was founded in 1997 with the name of *Fast link* and is a leading provider of mobile, broadband, and fiber internet services in the country. Zain Jordan is a subsidiary of the Kuwaiti telecommunications company Zain Group and has a strong presence in the Middle East and North Africa region. The company offers a range of internet packages for both residential and business customers, with a focus on providing fast and reliable connectivity. In addition to its internet services, Zain Jordan also offers a range of other telecommunications services, including mobile, fixed line, and TV.
- Orange: a mobile operator and ISP that offers broadband, fiber, and wireless internet services. Orange Jordan is a telecommunications company based in Jordan that offers internet service as well as mobile, fixed line, and TV services. It was founded in 1998 with the name of Mobilecom but now it is a subsidiary of the French company Orange. The company is a major provider of broadband, fiber, and mobile internet in Jordan and has a significant presence in the Middle East and North Africa region. Orange Jordan

offers a variety of internet packages for both residential and business customers, with a focus on high-speed and reliable connectivity.

*There are more service providers in Jordan than the mentioned before, but they offer their services only to the cities of Irbid, Amman, and Aqaba. Also, those three providers have the bigger share of the market.

The study has adopted maps of Ookla that shows the coverage and internet speed of the three providers using the speed test survey that depends on the reports of more than 8000 internet users in the households in Jordan. For this, data extracted from Ookla was used. 8000 users are not well representing the 11 million population, but the study had decided to use Ookla data because of two main reasons: first, while reviewing all the related studies and reports of the national statistics department in Jordan, and the annual reports of all ministries, up to date data was not found. The second reason is that TRC uses Ookal database, which is approved by Zeid Alkadi, director of licenses and consumer affairs, telecommunications Regulatory commission in Jordan.

“TRC Jordan is committed to the development of accessible, reliable broadband and mobile internet access. Ookla data helps us access the performance, quality, and coverage of mobile networks so that we can hold operators accountable for their networks, promote competition, inform policy decisions, and allocate funding appropriately, resulting in faster, more accessible networks for our constituents,” clear by the words of Zeid Alkadi, Director of licenses and consumer affairs, telecommunications regulatory commission in Jordan.

Pharmaceutical manufacturing in Jordan

In this thesis the discussion is about the pharmaceutical manufacturing and the I4.0 adoption in this economic sector in Jordan. Therefore, after discussing the economy in Jordan, the next step is going to be the pharmaceutical manufacturing in Jordan. This is followed by a review of what of the I4.0 emerging technologies are used in pharmaceutical in the world not only in Jordan. This will lead to the understanding of which are used before we move to I4.0 in Jordan.

Pharmaceutical Industry started in Jordan in the year 1962, in that year the Al-Arabiya company for pharmaceutical products was established with a capital of 150,000Jordanian dinar, which is still existed with the name of The Arab Pharmaceutical Manufacturing. After that, during the

1970's, the second company and factory were established, named Dar Al-Dawa'a for Development and Investment. It was created in 1975, followed by Al-Hikma Pharmaceuticals in 1977. Now the pharmaceutical industry in Jordan has 155 facilities that produce pharmaceutical products and human medicine according to the records of registered factories of the Amman Chamber of Industry, but those companies are mostly SMEs. In 2017, the pharmaceutical industry in Jordan took a big step = introducing themselves to the global market by using the global systems for Pharma Regulatory Affairs which was a result of the four research institutions that support them based on the agreements of the Jordanian association of pharmaceutical manufactures JAPM (Alabbadi, 2015b).

The importance of the pharmaceutical industry in Jordan occupies a special significance as it supports the national economy and revitalizes the industrial and economic sectors. The increase in pharmaceutical exports has achieved several gains for Jordan, the most important of which is supporting and strengthening the tax base, creating job opportunities, and supporting and strengthening the local economy due to the abundance and multiplicity of industrial establishments in this sector. The pharmaceutical industry sector is a major contributor to the national economy through exports, especially since Jordan exports about 80% of its production in this sector through 16 factories to more than 70 countries in the world. Including the United States of America and the countries of the European Union. The Jordanian pharmaceutical industry is considered one of the best local industries that achieve profits in foreign currencies(M. Alomari & Saqfalhait, 2015).

The pharmaceutical industry in Jordan is burgeoning, with several multinational companies headquartered in Jordan. These companies manufacture a range of products, including vaccines, cancer medications and generic drugs. Despite this success, the Jordanian pharmaceutical industry is lagging others in the region in terms of research and development of new medicines. This is mainly due to the high cost of clinical trials and the need for robust government subsidies. If these trends continue, the future looks bright for the Jordanian pharmaceutical industry(Al-Shaikh et al., 2011).

Jordan boasts around 155 pharmaceutical companies that produce a wide range of products. These companies have supplied countries around the world with high quality pharmaceuticals since the early 1960s. They have also been instrumental in educating local citizens about their health and how to protect themselves from preventable diseases (Alabbadi, 2015a).

According to the Organization for Economic Co-operation and Development (OECD), the pharmaceutical sector contributes around 3% of GDP to Jordan's economy every year. While this may seem like a small figure, it represents a significant percentage of the domestic economy and bodes well for the industry's future growth. Some of the top companies in the Jordanian pharmaceutical industry include AstraZeneca, GlaxoSmithKline, Sanofi and Pfizer. One of the main challenges facing the Jordanian pharmaceutical industry is a lack of research facilities. Most of the pharmaceutical companies are based in urban areas, making it difficult for them to access enough raw material for research purposes. This lack of resources has forced many companies to outsource their research facilities to neighboring countries such as Saudi Arabia or Egypt. In the long run, this will reduce the country's output in the pharmaceutical sector and make it less competitive in the international market (Alabbadi, 2015b). The government should therefore take active steps to increase investment in R&D facilities and encourage more companies to conduct research locally. This will also create jobs and boost the local economy in the long run.

The Jordanian Association of Pharmaceutical Manufacturers (JAMP)

The Jordanian Association of Pharmaceutical Manufacturers (JAMP) is a non-profit organization that represents the country's pharmaceutical industry, a major contributor to Jordan's economy. The majority (95%) of Jordan's pharmaceutical production is carried out by 14 full member pharmaceutical manufacturing companies, with four contract research centers serving as affiliate members. Membership in JAMP is voluntary, the 14 pharmaceutical corporations have chosen to join it. JAMP's mission is to help the Jordanian pharmaceutical industry, which exports most of its products, maintain high standards of quality, safety, and affordability through technology transfer, industry integration, and the implementation of Good Manufacturing Practices. JAPM has only 14 fully active members that manufacture pharmaceutical products and the following are the names of those factories.

1- Amman Pharma Industries Co. (API) based in Amman, Jordan. API produces a range of generic and branded drugs, including over the counter (OTC) and prescription medications. API's product portfolio includes medications for the treatment of cardiovascular disease, diabetes, respiratory illness, and other medical conditions. API exports its products to countries in the Middle East, North Africa, and Southeast Asia. The company was founded in 1979.

2- Arab Pharmaceutical Manufacturing Co. (APM) Arab Pharmaceutical Manufacturing Co. (APM) is a pharmaceutical company that is based in Jordan. APM was established in 1988 and is one of the leading pharmaceutical companies in the Middle East and North Africa region. APM produces a wide range of pharmaceutical products, including generics, branded generics, and proprietary products. The company has a strong focus on research and development and has a state-of-the-art manufacturing facility in Irbid, Jordan. APM exports its products to over 50 countries worldwide and has a strong presence in the Middle East and North Africa region.

3- Dar Al Dawa Development & Investment (DAD) Dar Al Dawa Development & Investment (DAD) is a healthcare and pharmaceutical company based in Jordan. The company was founded in 1979 and has grown to become one of the leading healthcare and pharmaceutical companies in the Middle East and North Africa region. DAD has a strong focus on research and development and has a state-of-the-art manufacturing facility in Amman, Jordan. The company produces a wide range of pharmaceutical products, including generics, branded generics, and proprietary products. DAD exports its products to over 50 countries worldwide and has a strong presence in the Middle East and North Africa region. In addition to its pharmaceutical business, DAD also operates several hospitals and clinics in Jordan and the region.

4- Hayat Pharmaceutical Industries Co. (HPI) Hayat Pharmaceutical Industries Co. (HPI) is a pharmaceutical company based in Jordan. HPI was established in 1983 and is one of the leading pharmaceutical companies in the Middle East and North Africa region. The company has a strong focus on research and development and has a state-of-the-art manufacturing facility in Amman, Jordan. HPI produces a wide range of pharmaceutical products, including generics, branded generics, and proprietary products. The company exports its products to over 50 countries worldwide and has a strong presence in the Middle East and North Africa region. In addition to its pharmaceutical business, HPI also operates several hospitals and clinics in Jordan and the region.

5- Hikma Pharmaceuticals is a global pharmaceutical company that is based in London, United Kingdom. The company was founded in 1978 and has grown to become one of the leading pharmaceutical companies in the world. Al-Hikma has a strong focus on research and development and has a global manufacturing network that includes facilities in the United States, Europe, and the Middle East. The company produces a wide range of pharmaceutical products, including generics, branded generics, and proprietary products. Hikma has a strong presence in the Middle East and North Africa region and exports its products to over 50 countries worldwide. In addition to its pharmaceutical business, Hikma also operates a number of hospitals and clinics in the Middle East and North Africa region. Hikma Pharmaceuticals has a strong presence in Jordan, where it has a number of facilities and operations. The company has a state-of-the-art pharmaceutical manufacturing facility in Amman, Jordan, which produces a wide range of generic and proprietary products for the global market. Hikma also has a research and development center in Amman, where it conducts research on new pharmaceutical products and technologies. In addition to its pharmaceutical business, Hikma also operates several hospitals and clinics in Jordan, including the King Hussein Cancer Center and the Jordan Hospital.

6- Jordan River Pharmaceutical Industries (JORIVER) Jordan River Pharmaceuticals (JoRiver) is a limited liability company that was established in 1999 in Mobis, Jordan. JoRiver develops and manufactures a wide range of more than 50 pharmaceutical products in compliance with international Good Manufacturing Practice (GMP) guidelines and procedures; as well as The Total Quality Management (TQM). Also, JoRiver facilities gained Jordan Food and Drug Administration (FDA), ISO 9001 and ISO 14001 accreditations. Moreover, JoRiver obtained GMP certificates from several countries including Gulf Cooperation Council (GCC), Jordan, KSA, UAE, Kuwait, Qatar, Bahrain, Oman, Iraq, Lebanon, Palestine, Sudan, Ethiopia, Libya and Algeria. To this end, the factory is reinforced by qualified competent staff and well-equipped departments. JoRiver has more than 100 employees from different disciplines including pharmacy, engineering, life sciences, and chemistry among others. JoRiver is organized into eight departments namely production and planning; quality assurance and quality control; maintenance; research and development; regulatory affair; finance and administration; sales and marketing; and management. Finally, JoRiver has three main production lines: (i) solid manufacturing; (ii) liquid manufacturing; and (iii) semi-solid manufacturing. JoRiver markets its medicinal products in more than 14 countries including Jordan; GCC countries (KSA, UAE, Oman, Bahrain, Kuwait, and Qatar); Yemen; Lebanon; Algeria; Ethiopia; Sudan; and Iraq among others. JoRiver aspires to be one of the local and regional leading pharmaceutical companies that produce the number one choice of high quality and safe drugs with the highest efficacy.

7- MIDPHARMA (Middle East Pharmaceutical & Chemical Industries) MIDPHARMA (Middle East Pharmaceutical & Chemical Industries) is a pharmaceutical company based in Jordan. MIDPHARMA was established in 2000 and has grown to become one of the leading pharmaceutical companies in the Middle East and North Africa region. The company has a strong focus on research and development and has a state-of-the-art manufacturing facility in Irbid, Jordan.

8- Pharma International Co. (PIC) Pharma International Co. (PIC) is a pharmaceutical company based in Jordan. PIC was established in 1988 and has grown to become one of the leading pharmaceutical companies in the Middle East and North Africa region. The company has a strong focus on research and development and has a state-of-the-art manufacturing facility in Amman, Jordan. PIC produces a wide range of pharmaceutical products, including generics, branded generics, and proprietary products. The company exports its products to over 50 countries worldwide and has a strong presence in the Middle East and North Africa region. In addition to its pharmaceutical business, PIC also operates several hospitals and clinics in Jordan and the region.

9- Pella Pharmaceutical co. is a leading pharmaceutical company based in Jordan that produces a variety of medications, including generic drugs, branded generics, and proprietary products. The company places a strong emphasis on research and development, and has a state-of-the-art manufacturing facility in Amman, Jordan. Pella exports its products to over 50 countries worldwide and has a strong presence in the Middle East and North Africa region. In addition to its pharmaceutical business, Pella also operates hospitals and clinics in Jordan.

10- Ram Pharmaceutical Industries is a pharmaceutical company based in Amman, Jordan that was established in 1992. It specializes in the manufacture and marketing of various pharmaceutical dosage forms. The company's factory is located in the King Abdullah II Industrial City and is divided into four different plants for specific product groups. The company covers a wide range of therapeutics, including antibiotics, anti-microbial agents, anti-parasites, anti-viral medications, anxiolytics and anti-depressants, capillary regulators, CNS stimulants, peripheral and cerebral vasodilators, anti-hypertensive agents, hormones, analgesics and anti-inflammatory agents, respiratory drugs, gastrointestinal drugs, iron preparations, anti-hyperglycemic agents, diuretics, and anti-gout preparations. In addition to the domestic market, Ram Pharmaceuticals exports its products to countries like Algeria and Iraq and is a certified supplier to the Ministry of Health in Jordan. The company holds ISO9001:2008 certification.

11- Sukhtian Pharma Co. is a pharmaceutical company based in Jordan. The company was founded in the 1960s and has grown to become one of the leading pharmaceutical companies in the Middle East and North Africa region. Sukhtian Pharma has a strong focus on research and development and has a state-of-the-art manufacturing facility in Amman, Jordan.

12- Sana Pharma is a pharmaceutical company based in Amman, Jordan that was established in 1992. It specializes in the manufacture and marketing of various pharmaceutical dosage forms. The company's factory is in the King Abdullah II Industrial City and is divided into four different plants for specific product groups. The company covers a wide range of therapeutics, including antibiotics, anti-microbial agents, anti-parasites, anti-viral medications, anxiolytics and anti-depressants, capillary regulators, CNS stimulants, peripheral and cerebral vasodilators, anti-hypertensive agents, hormones, analgesics and anti-inflammatory agents, respiratory drugs, gastrointestinal drugs, iron preparations, anti-hyperglycemic agents, diuretics, and anti-gout preparations. In addition to the domestic market, Sana Pharma exports its products to countries like Algeria and Iraq and is a certified supplier to the Ministry of Health in Jordan. The company holds ISO9001:2008 certification.

13- Total Quality Pharma Co. (TQPharma) Total Quality Pharma Co. (TQPharma) is a pharmaceutical company based in Jordan. The company was established in 2004 and has grown to become one of the leading pharmaceutical companies in the Middle East and North Africa region. TQPharma has a strong focus on research and development and has a state-of-the-art manufacturing facility in Amman, Jordan. The company produces a wide range of pharmaceutical products, including generics, branded generics, and proprietary products.

14- United Pharmaceutical Manufacturing Co. (United) United Pharmaceutical Manufacturing Co. (United) is a pharmaceutical company based in Jordan. The company was established in 1999 and has grown to become one of the leading pharmaceutical companies in the Middle East and North Africa region. United has a strong focus on research and development and has a state-of-the-art manufacturing facility in Amman, Jordan.

It is worth to mention that the net worth of the above mentioned is not clear. This kind of information is not shared with student and academic research rather; only the paid reports of market analysis are available.

Industry 4.0 in the pharmaceutical manufacturing in the world context, the concept of Pharma 4.0

The following part of the thesis focuses on the results of the bibliometric analysis, and the systematic literature review of the Pharma 4.0 study, followed by the analysis. Here in this part of the study, a bibliometric analysis has been done using both data bases of Scopus and web of science as it was mentioned in the methodology part of the study. The steps that have been done aimed to highlight what are I4.0 technologies which are being used in the pharmaceutical manufacturing. Conducting this search resulted in finding 96 documents on Scopus and 401 documents on WOS. After that the documents which included all the scientific publication types of Book chapter, Article, Book review, review article and conference proceedings. Using Vos viewer the top cited articles and most connected documents were reached.

This part of the study is going to review the topic areas of I4.0 in terms of pharmaceutical manufacturing, known as Pharma 4.0 In this way, most recent and related documents and the top cited documents will be covered. This chapter has subchapters based on the database used, two of which have been mentioned in the methodology. In each part the search, keywords are mentioned using the basic and advanced search tools to ensure the transparency of the results. At the beginning, the bibliometric analysis for each topic area related to Pharma 4.0 in each data base will be elaborated and visualized. Using the top twenty cited documents in each database then systematic literature review will take place, knowing that the chosen top cited documents must fit the criteria of inclusion that have been mentioned in the methodology part.

us Using Vos viewer and the systematic literature review to highlight the top twenty related documents led to the core concept of the research which is using Industry 4.0 emerging technologies in pharmaceutical manufacturing. To reach these results, the following search query has been used:

TITLE-ABS-KEY ((“Pharmaceutical”) OR (“pharma*”)) AND ((“industry 4.0*”) OR (“fourth industrial*”) AND (“manufacturing*”)).

The justification of using these keywords here in the part of the study was because the I4.0 Pharmaceutical manufacturing known as Pharma 4.0, where in other research it was mentioned as the pharmaceutical manufacturing in Industry 4.0. Choosing Industry 4.0 instead of mentioning each technology on its own was intended to reach to most connected researchers. Then this query was applied in the Scopus database. It is possible to see in figure number 11 the search results after using Vos viewer to analyze the data based on the citation score of the documents, which were, in total, 401 documents, including book reviews, review articles, book chapters, and conference proceedings.

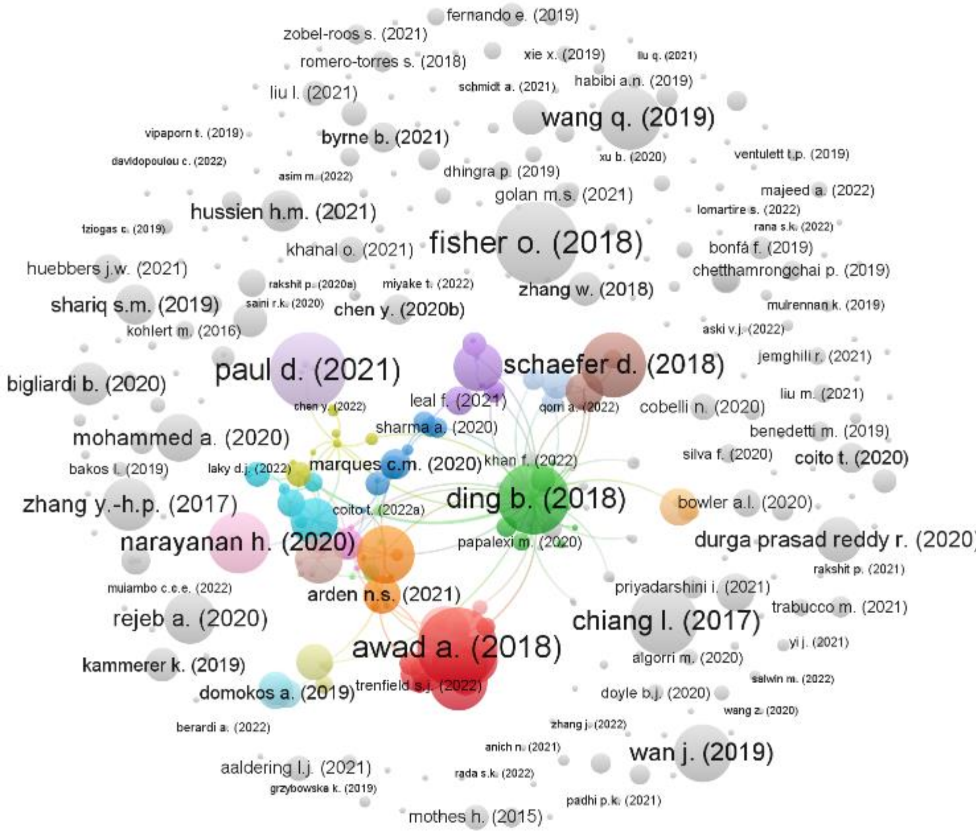


Figure 10 research result analysis of Scopus database using the document as the unit of the analysis (source Vos view and Scopus data base)

After running the analysis using Vos viewer it was noticed that in the 401 documents there were a connection based on the citation's links between only 138 documents, as we can see in the figure number 4 below. In this, the unit of analysis was the document rather than the author. This way, we can reach the most connected documents in relation with the research questions and hypotheses. If we look at the figures we can see that each DOT or circle is not only representing the document, but it also shows the author's names. Using Vos viewer software, by clicking on any dot, it can lead to the document online. The second point is exporting the data file from Scopus to be used in Vos viewer. Please not that according to Vos viewer manual only (Microsoft Excel Comma Separated Values File (.csv)) can be analyzed. .

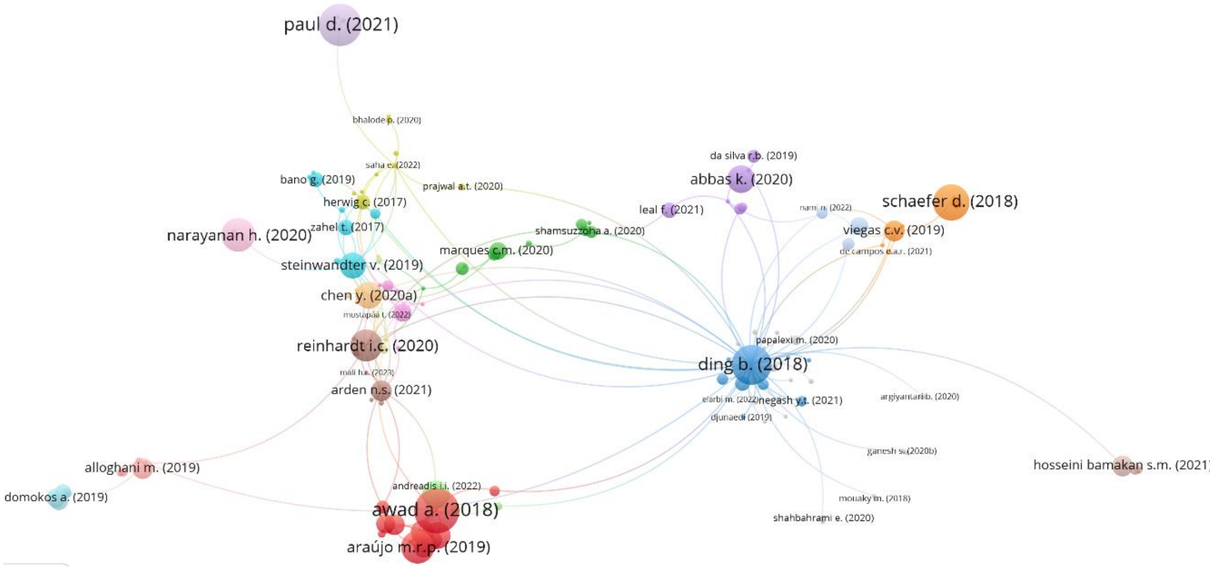


Figure 11 research result analysis of the most connected (138) documents of Scopus database using the document as the unit of analysis (source Scopus data and Vos viewer)

In figures 11 and 12, we can see the most connected documents in the data base of Scopus. The lines between the dots represent the citation connections between those documents. These citations are defined by links in Vos viewer software The dots names reflect the author name/s and year of publication. We can notice that only 138 of around 400 are connected, number which can demonstrate the collaboration between the authors.

Web of science analysis in terms of pharma 4.0 concept in the world

Using the web of science database to reach for the desired data was done through using advanced and basic search in that way we can assure that all the related documents are included. Because using basic search was better in including all the related documents in the search. The following keywords were used for a search in topic, abstract, title, and keywords: Industry 4.0, Pharma 4.0, Pharma manufacturing. The results were as the following:

94 documents were found in the database which are related to the topic areas in the time span between 2018 and 2022, only in English. The documents were book chapters, articles, review articles, conference proceedings and corrections. After, the Vos viewer analysis was used, based on documents citation as the unit of analysis. The result was only of 22 documents out of 95 which were connected based on the links of the citations. In figure number 5 we can see the documents and in figure number 6 we can see the most connected articles. This is the same case of Scopus, in which documents had high score of citations, but were not connected, based on

the citation links to the rest of the found documents. In the case of using Vos viewer to analyze the search results the following must be followed.

Referring to the manual of Vos viewer, the accepted format for using it could be text file type or Tab Delimited File, but in this thesis Tab Delimited File was used instead. This is the case of using the database of Web of science.

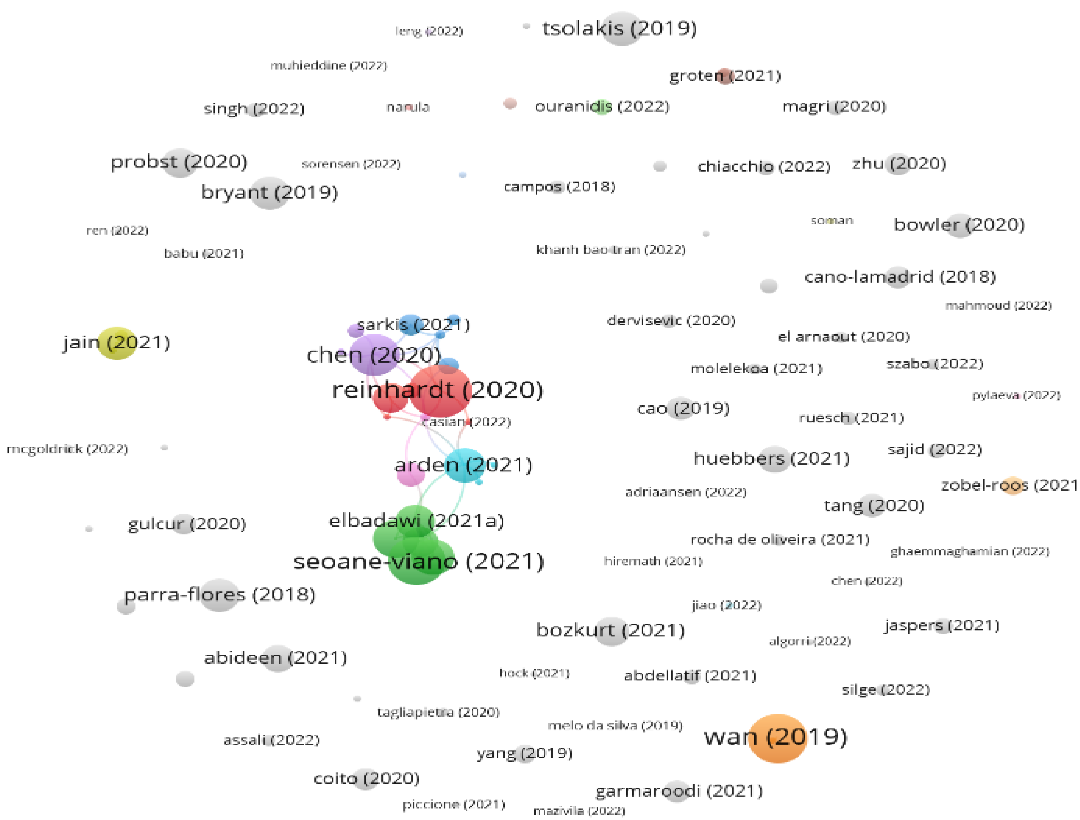


Figure 12 research result analysis of web of science data base using the document as the unit of the analysis (source Vos view and web of science data base).

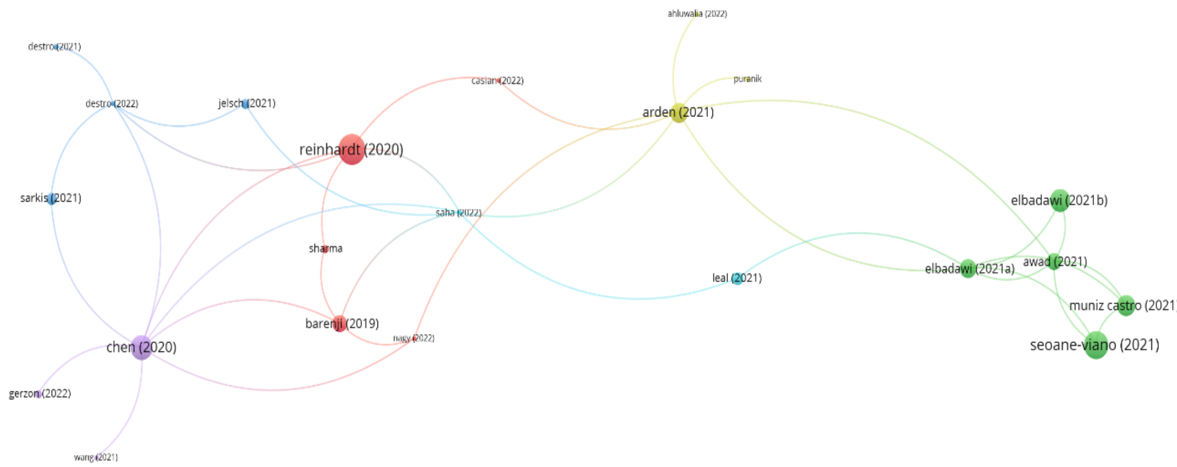


Figure 13 research result analysis of the most connected (138) documents of web of science data base using the document as the unit of the analysis.

Using both databases and running the analysis based on the citation score and based on the inclusion criteria in the following tables we can see the top twenty cited documents.

Table 6 top cited articles using Web of Science WOS

Number Of citations	links	Document title	Journal name	Journals impact factor	journals cite score
63	5	Current Perspectives on the Development of Industry 4.0 in the Pharmaceutical Sector	Journal of Industrial Information Integration	11.718	20.9
55	1	Reconfigurable Smart Factory for Drug Packing in Healthcare Industry 4.0	IEEE Transactions on Industrial Informatics	11.648	21.3
50	3	Translating 3D printed pharmaceuticals: From hype to real-world clinical applications	Advanced Drug Delivery Reviews	17.873	22.3
40	8	Digital Twins in Pharmaceutical and Biopharmaceutical Manufacturing: A Literature Review	Processes	3.352	3.5
33	2	Additive Manufacturable Materials for Electrochemical Biosensor Electrodes	Advanced functional material	19.924	N/A

28	3	Machine learning predicts 3D printing performance of over 900 drug delivery systems	Journal of Controlled Release	11.467	15.7
26	7	Industry 4.0 for pharmaceutical manufacturing: Preparing for the smart factories of the future	International Journal of Pharmaceutics	6.51	9.6
24	2	Modelling the enablers of industry 4.0 in the Indian manufacturing industry	International Journal of Productivity and Performance Management	3.99	0.578
24	6	Harnessing artificial intelligence for the next generation of 3D printed medicines	Advanced Drug Delivery Reviews	17.873	22.3
20	0	3D printing technology; methods, biomedical applications, future opportunities, and trends	Journal of Materials Research and Technology	6.267	5.9
20	5	Connected healthcare: Improving patient care using digital health technologies	Advanced Drug Delivery Reviews	17.873	22.3

Source dissertation contribution using excel and VOS viewer / rest of the tables can be found in appendix number 1.

<u>Scopus data base findings and analysis in terms of pharma 4.0 concept in the world</u>

<u>Table 7 top cited articles on Scopus data base related to Pharma 4.0</u>

Citations	links	Document title	Journal name	Journal impact factor	Journals cite score
152	0	Cloud manufacturing as a sustainable process manufacturing route	Journal of Manufacturing Systems	9.498	15
140	9	Reshaping drug development using 3D printing	Drug Discovery Today	8.369	14.7
127	4	Artificial intelligence in drug discovery and development	Drug Discovery Today	8.369	14.7
113	47	Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains	Process Safety and Environmental Protection	7.9626	9.9
102	0	Big Data Analytics in Chemical Engineering	Annual Review of Chemical	9.7	N/A

			and Biomolecula r Engineering		
95	3	Smart Packaging: Opportunities and Challenges	Procedia CIRP		3.9
86	0	Green technology innovation development in China in 1990–2015	Science of The Total Environment	10.753	14.1
82	3	Bioprocessing in the Digital Age: The Role of Process Models	Biotechnolog y Journal	3.543	
75	3	The Digital Pharmacies Era: How 3D Printing Technology Using Fused Deposition Modeling Can Become a Reality	Pharmaceuti cs	6.525	
74	0	Reconfigurable Smart Factory for Drug Packing in Healthcare Industry 4.0	IEEE Transactions on Industrial Informatics	11.648	21.3

If we analyze table 2 and 3, we can see the top twenty documents in the data base of both Web of science and Scopus. The two databases had similarities and differences. Knowing that same key words of search were used by the author during the search, we can notice something important: in the case of the WOS we can see, relatively, that the impact factor of the journals are higher. In this case, we can mainly notice that the documents found in WOS are more important. However, we can't say that the information found in the database of Scopus is useless. Therefor both data sets were used as material for analysis, based on the citation score of the document as the analysis parameter. Also, an important thing must be mentioned, that, usually, the researchers in the field of medical studies are relatively more citied than others because of the importance of this domain in the sustainability goals of the world. The documents which have been found on the databases of WOS and Scopus were collected, reviewed, and elaborated for better core information extraction.

All the documents found in the two tables are related to Industry 4.0 emerging technologies. They cover the topic of Industry 4.0 technologies in relation of Pharmaceutical and health sector. Some of the most discussed technologies are additive manufacturing 3D printing, IoT, simulation, C.C and big data. Also, there was a focus on the other technologies. These topic areas are important to this sector because of different factors: 3D printing of both sensors and drugs. Those two are important to reach a new age of health care. It is undeniable that other technologies are also important, since all technologies of Industry 4.0 are related to each other. The use of sensors in health care was not only part of this Industrial Revolution, but rather it goes back to 1956, when the first biosensor was developed for oxygen detection. Health care sensors which are mostly named Biosensors have been used in car seats, to measure blood pressure and even more. Nowadays it can be seen in smart phones and as well in the smart watches people use. In some studies, the discussion of sensors went as far to the printing of sensors; not only printing, but rather more into the discussion of what materials that can be used to print them, layer by layer. For further details, this thesis is recommended (Elbadawi, Ong, et al., 2021). This study can explain in detail how the evolution of biosensors in health care happened. Also, it demonstrates its importance in highlighting the materials which can guarantee less cost and time in printing. Also, in this thesis, we can find the methods of 3D printing that have been found to be more effective in material consuming and overall quality. This study can be used in detecting cardiovascular system as well as other vital signs. Moreover, 3D printing can be used in the biomedical industry not just to produce medicine but more into the printing of bones, teeth and 3D printed disease modeling (Bozkurt & Karayel, 2021; Elbadawi, McCoubrey, et al., 2021; Muñiz Castro et al., 2021). In a different aspect, we can see that this study (Gülçür et al., 2020) focuses into manufacturing monitoring process to achieve less errors. It can be noticed that it has a high citation score because this document has a considerable amount of details about the process and not only about the necessary material, which makes it helpful for the researchers who are into reducing the time and cost of manufacturing in pharmaceutical industry.

Also, it provides ideas of materials that can be found in the manufacturing process which do not belong to the product, since the polymers or the nano parts of it can dissolve in some of the production process due to, for example, high temperature. Also, the use of sensors is not only for monitoring patients but rather we use sensors in each step of our daily life: in house doors security, or in the use of a heating system. However, using sensors can reduce the time of manufacturing and the raw material control. Thus, the industry of food beverages and pharmaceuticals products usually relay on mixing materials with each other; in this process, the use of mixing sensors can enhance the management of the production lines in a timely matter and resources management matter as well, this thesis can conclude that the use of mixing sensors without stopping the manufacturing process in an experimental method approach (Bowler et al., 2020).

One important element of pharma manufacturing is mixing that now relaying on sensors. A fundamental element of mixed materials in the pharma and/or food industry is water. A study in the data base concludes all the related issues of water in the products using sensor, ML which was the reason for this document to be part of the researched database of this thesis (Garmaroodi et al., 2021). In other issues related to Industry 4.0, the logistics part is very important to give indications to the decision makers over the production and manufacturing; in this matter, we can notice the use of the old systematic ways to manage the quality of the manufacturing and the delivery of the pharmaceutical products.

By mentioning old methods of quality control and scenario drawing we can always refer to the Japanese ways of management and feasibility studies. For example, 5S, Kanban, Just-In-Time, fishbone diagram and Heijunka, are some that can be mentioned. All of these methods meant to incorporate an Agile method of production and total quality control. In the pharmaceutical industry, it is important to achieve the maximum degree of safety levels. We can see stream mappings and event simulations in different software but for one, which was the main tool for this study: *Any logic*, which was studying the implementation of such Industry 4.0 technologies in pharmaceutical manufacturing, only in the logistics, to improve the decisions of the decision makers over those facilities. (Abideen & Mohamad, 2021) In this study we can relate that old methods are the base knowledge of the new technologies used in Industry 4.0. Abideen and Mohhamd focused on using charts, drawings and related materials, focusing on the warehouse implications rather than the whole manufacturing. All these implementation of industry 4.0 technologies can enhance inventory management which can lead to more effective customer support, time and resources management. Which are pouring into the sustainability cup of avoiding errors in such industry that can affect the human wellbeing.

The use of Industry 4.0 emerging technologies in pharmaceutical industry as well in other industries is called the goldmine of bigdata and cloud computing. Those together can be the base of the simulation, AI, Machine Learning and system integration. To adopt these technologies in the pharmaceutical industry some methods must be used to have the maximum competitive advantage. An important issue to remember in the food and pharmaceutical industry is the regulatory affairs; many organizations are aiming to produce medicine and food products according to the U.S. Food and Drug Administration FDA and EMA European medicine agency policies. In relation with producing such products there are always challenges the decision makers must face to contribute and relate to those pharma regulatory affairs. With the presence of the Data fusion, new opportunities and challenges were recognized. Into this discussion also came a document which was not of the top citied ones, but which, yet, is connected to most of the data set. A dissertation that discusses this topic in details is (Casian et al., 2022). This document reviews the challenges and opportunities that DF are representing by conducting a review of all the related reviews in those area of topics with the aim to apply more quality control in one of the strictest industries. Pharma 4.0 is aimed to integrate the use of industry 4.0 emerging technologies as an automated manufacturing and the use of data is the main attribute to connect devices together using IoT or IIOT. In a timely matter and raw material management to reduce costs, Industry 4.0 applications have reduced the manufacturing to more than 10% in each stage of manufacturing.

According to the previous studies in the health and safety issues of pharma manufacturing, the use of irregulated drugs has caused the death of over 100,000 deaths annually and over $200 billion loses in the pharma industry (Chiacchio et al., 2020). It was found that the consumer relationship is important to formulate trust, this could be achieved in a decentralized way. This decentralized way was achieved before in many cases by using the blockchain technologies, “a decentralized, immutable shared ledger that can be applied to a variety of business settings involving transaction processes”(Musamih et al., 2021) (Chiacchio et al., 2022). So, the main idea of using NFT non-fungible token to avoid risks in the supply chain of the pharma industry in a decentralized method is to use this technology of Industry 4.0, meaning, the blockchain and particularly NFT. Using this technology in the supply chain management of pharma industry can the bring the advantage of security, traceability, immutability, accessibility of data provenance, according to (Chiacchio et al., 2022) whose studies show how this technology is used. But on the other hand, the use of blockchain technology can be seen as against the VUCA (volatility, uncertainty, complexity, ambiguity) method of risk assignment where this market of decentralized currency or known as the cryptocurrency is a volatile market. Thus, the proposal of(Chiacchio et al., 2022), it is how the approach of NFT “can strengthen the track and trace process, improve the communication among the supply chain stakeholders, and increase trust with the final consumers" (Chiacchio et al., 2022). An important topic in most of the studies regarding Pharma 4.0 is the need of a "digital twin", defined as a digital representation that mirrors a real-life object, process, or system. We can define it as a way or type of simulation. It is not a new idea. It has been used before to computer aided design representations of things or online profiles of customers. This was before the massive integration of the new technological systems in the production of pharma products or more in the manufacturing era. The digital twin methods in manufacturing are no longer only just computer aided, but rather it focuses on IoT sensors data that can provide a better maintenance experience because of the real time data from IoT sensors, and the main computer in the production lines, which receive the sensors data and analyze it using ML. Production lines are usually complex systems with many undocumented processes which, in most cases, lead to failure. But using digital twin is designed to cope with the complexity of the systems. The digital twin allows us to have better decisions over the use of raw materials and how the outcomes will look like(Chen et al., 2020).

One of the benefits of using digital twin systems is the possibility of monitoring which of the production activities consumes the most energy. Considering that the degree of automation is quite high, starting in petrol and chemical production, it was registered that 40% of the energy is used in the chemical process industry, and this was due to the necessary maintenance. By this example, we can see how the digital twin was reflected, where the energy consumption was concentrated, and we could fix it in this matter of energy consumption(Zobel-Roos et al., 2021).

In regards of the I4.0 and energy consumption as well cost we can take Germany for example. It can be noticed that 40% of the consumed energy in manufacturing in Germany was spent in petrochemical products manufacturing in materials separation processes. Nevertheless, industry overall accounts for only about 30% of German energy consumption, whereas Centre for Health and the Public Interest participates with about 30%, in relation to steel industry consume 20% and cement 10%. Clean and renewable energy can be the concept which will achieve Industry 5.0 concept of fully closed automated system but still if we look at the German case we can see that their win d mil farm is only producing 5% of the needed energy. But of course Germany is leading by example in this advanced industries and they have the fusion reactor project which is the answer to all the energy concerns. Fusion reactor is huge topic cannot be explained here but yes indeed it will be the next step in these advanced technologies toward real time Industr5.0.

In here we can conclude that the generation of a “Digital Twin” must be effectively set off about “maintenance, product yield, operational robustness and much more applications.

We can also conclude that the use of industry 4.0 is widely effective in pharma industry, yet many countries and human rights organizations are rejecting the automated manufacturing in the pharma production without human intervention in the quality control of it.

Based on the literature analysis, using Industry 4.0 can bring a better experience for the consumer in the field of Pharma production. Using 3D printing drugs is not just something fancy to be done but we can perceive it as a reduced energy process comparing with the old methods; also the fact that we can have special printed drugs for special patient. The use of advanced sensors, we can monitor the health of the patient while they are at their homes, which will make hospitals less crowded. Using the sensors, we can see the levels of *ph.* or any related chemistry in the human body and we can modify and prescribe the needed medicine based on that.

Indeed, Industry 4.0 emerging technologies are empowering the industry which needs huge amounts of energy and research. It is necessary, though, to acknowledge three main concerns. The first concern is related to the necessary raw materials to produce the nano semiconductors, deeply involved with these technologies; the second, the high energy consumption and CO2 emissions produced by the process as a whole; the third, the risk of building self-conscious AI.

Industry 4.0 in Jordan

The new emerging technologies are not just important in Jordan’s but rather worldwide manufacturing as well. (Kagermann, Helbig, et al., 2013). When we look at the emerging technologies of industry 4.0, we can see that I4.0 applications relay mostly on the connections between the machines as well as it does relay on the algorithms of Machine learning. This and more of these technologies are important in reducing the time and cost of manufacturing; more important the aim is to have higher quality of the services and products. (Lasi et al., 2014). As mentioned, the covid crisis opened our eyes to the possibility of using those systems as a contingency plan to tackle many crises; this is what autonomous robotics and the smart factory comes in place for. (Bakos et al., 2019; Castillo, 2016; Nickinson et al., 2020). Here we can conclude the relation of I4.0 emerging technologies, crisis management, pharmaceutical manufacturing, and Jordan as a common topic. It is proved that Industry 4.0 enhances the quality of products; two of the biggest markets in world are the food and beverages industry, and on top of it, the pharma Industry. In Jordan, pharma industry is known to be regulated with the FDA, MENA Pharma standards, and the European Medicines Agency (**EMA).** In fact, there are only fourteen pharma products producers in Jordan who are approved out of 155 organizations in Jordan. Those 14 have their own association called *The Jordanian Association of Pharmaceutical Manufacturers* (JAPM). This association is considered to be the most advanced in terms of manufacturing technologies in Jordan (Alomari et al., 2015). However, there is no real evidence that those organizations have adopted the smart factory applications; in fact, there is only one study has been done in Jordan which refers to this fact: "the information technology culture in Jordan is not mature enough to support cyber–physical systems, interoperability, and IIoT, which are essential parts of the infrastructure for efficient digital data systems" (Shqair & Altarazi, 2022). In all studies that have been made about the Jordanian economy and adopting Industry 4.0, there were no real implementations of such systems, or even interviewing the Industry 4.0 experts, as it is found in the interview manifest "top management level in the pharma industry in Jordan have mentioned that they are using Industry 4.0 applications which is in fact not true but this was to have the funds of the EU project to adopt Industry 4.0 technologies in Jordan

From those statements, we can notice that the study problem highlights what are the reasons that affect industry in Jordan, to adopt Industry 4.0. Previous studies have recommended the analysis of the pharma industry in Jordan to see what are the challenges which prevent them from adopting these technologies. (Al-Zyadat et al., 2022; Shqair & Altarazi, 2022). After the tests done to SMEs in Jordan, studies were conducted to understand what influences drivers more than challenges are. Only one study has done enough about the energy challenges in the pharma industry in Jordan and the opportunity to adopt renewable anergy solutions solar power (Haagen et al., 2015). And this opportunity can be seen in the government's reports of 2020. One last important thing is that in Jordan, the unemployment rate reached up to 50% among the youth, which turns the adoption of Industry 4.0 emerging technologies; it is known that it does require highly qualified work force only, this kind of workforce is called Operator 4.0 (Fantini et al., 2020) (Hecklau et al., 2016)(Armstrong et al., 2019).

Another important element of this thesis is that in the last three years, the EU started to fund the project of I4.0 with the partnership of Sam Engineering from Jordan, Transition Technologies–Advanced Solutions from Poland. At the beginning of the project, there were two more companies involved in it, and those two companies left the project: *Ibtecar*, from Jordan, and *Tum technologies,* from Germany; more will be explained about the limitations of the study. This project which was funded by the EU is concerning the I4.0 solution and the training of the human power in the Jordanian economy and labor market.

3. Quantitative and qualitative analysis

In this chapter of the dissertation, two main parts should be considered; the first part will be the qualitative part of the study, which leads to its second part. In the first place, it was necessary to analyze many steps to reach the possibility of investigation of the Industry 4.0 in Jordan; generally, and specifically the Jordanian pharmaceutical manufacturing. In the first step, as previously visited, part of the thesis investigated what are the main skills and competencies of Industry 4.0. To reach that, a survey was conducted on twenty professionals in the IT sector of multinational companies in Budapest, Hungary. After that research, we have reached to the most important issue: to have the human as the center of I4.0. Then, an interview was conducted with the project managers of EU funded Industry 4.0 project in Jordan. This was the qualitative part of the study. This part was done using in-depth interview and it was analyzed using what is called thematic analysis. The second step was creating the hypothesis and the study tool that represents the quantitative part of the study which can be found in the second part of this chapter.

3.1 Qualitative analysis and results (EU funded Industry 4.0 project in Jordan)

Investigate industry 4.0 project in Jordan using (qualitative method) in-depth interview with the mangers of Industry 4.0 project in Jordan; to highlight what are the real challenges that holds the Jordanian pharma manufacturing from adopting the emerging technologies of Industry 4.0. only two mangers were interviewed: one face to face and the other was done using Microsoft teams, which was done during August and September of 2022. More details about the project and project partners will be in the Industry 4.0 project in Jordan part of the study. the analysis of the interview was made using thematic analysis to match the answers of the experts to the study questions. In this type of data collection there is no clear minimum or enough participants in the interview where in fact the study community in the qualitative research part was the number of the 4 organizations participating in the project (Bernard & Ryan, 1998). Applied thematic analysis were used to analyze the interview textual data which was generated from audio files in first place according to (Guest et al., 2012). While searching online for related

research and documents which have been written about the manufacturing in Jordan, it was a must to conduct researches on the search engines outside of the research and academic resources. In this way we can ensure the results of the study were verified. The project of Industry 4.0 in Jordan was found using these online searches. Before moving to the project, in the figure below, there is a map of the documents found on Scopus database in regards of industry 4.0 in Jordan. Only four documents have been found in regards of industry 4.0 in Jordan.

Figure 14 industry 4.0 in Jordan Source (Scopus data base and Vos viewer).

After reviewing these documents, it became clear that they were more of a literature review than, in reality, a new study. (Shqair & Altarazi, 2022). Here in this document, they have confirmed by speaking with Industry 4.0 experts and studying the SMEs in Jordan that there were no implementations of industry 4.0.

1. It is the aim of this study to have a better investigation in this I4.0 project and adopt the topic of pharma industry in Jordan The first step was to conduct a search online about this project. There are no clear ideas about the project budget or any specifications about the project itself. These points became the main aim of the research

After conducting the search online using all the available search engines, it was discovered that the project partners are 5 bodies of companies and the EU delegation in Jordan: *Ibtecar*, from Jordan; *Sam Engineering*, from Jordan; *Transition Technologies Advanced Solutions*, from Poland; and *TuM*, from Germany). At first, the EU delegation in Jordan was contacted, and clearly after more than one hour on the phone, it wasn't possible to reach to anyone who is aware of the project. At a second attempt of contacting the EU delegation in Jordan, and after complex chain of calls, it was impossible to find anyone who knows what Industry 4.0 means or even IoT.

After a secondary attempt to reach the partners in the project, the first one to replay was *Ibtecar*. which "is a company specialized in providing innovation services to companies, organizations, and communities to enable sustainable growth. This is done through customized innovation programs development covering innovation policies, structures, processes, strategies, and organization culture. Moreover, it provides coaching, training and certification in Creative Thinking, Intellectual Property rights, entrepreneurship, and research strategies". After conducting the interview (whose questions can be found in the following lines and in *Appendix Number 2*) with the top management level, a research about the project was conducted.

- What is the fact of industry 4.0 in Jordan?
- What is the level of awareness about Industry 4.0 technologies in Jordan?

- What are the challenges that are facing the Jordanian industry from adopting such technologies?
- What are their contributions in the project?
- What they think about the skills needed for the industry 4.0?
- What are the skills that can serve Industry 4.0 and can be a recovery in case of system down?
- What is the fact about the Industry 4.0 project in Jordan?

So, the interview here was not formatted in systematic way, where the interviewer asks specific questions or lead the interviewed person to give a desired answer, but rather asking questions in way to leave all the comments to experts. Two successful interviews happened. One with *Ibtecar* and the other with the project manager of Industry 4.0 in Jordan. Investigate industry 4.0 project in Jordan using qualitative method's in-depth interview with the mangers of Industry 4.0 project in Jordan; to highlight what are the real challenges that hold the Jordanian pharma manufacturing from adopting the emerging technologies of Industry 4.0. Only two managers were interviewed: one face to face and a second one who was interviewed using Microsoft teams; these interviews happened between August and September of 2022. More details about the project and project partners will be more deeply considered and developed in a further section, revolving around the Industry 4.0 project in Jordan. The analysis of the interview was made using thematic analysis to match the answers of the experts to the study questions. In this type of data collection there is no clear minimum or enough participants in the interview where in fact the study community in the qualitative research part was the number of the 4 organizations participating in the project (Bernard & Ryan, 1998). Applied thematic analysis were used to analyze the interview textual data which was generated from audio files in first place according to(Guest et al., 2012).

Two out of four companies left the project for reasons they didn't share. The two companies are: *Ibtecar,* from Jordan and *TuM,* from Germany. When asked about leaving the project, the CEO of *Ibtecar* said that there is no real manufacturing in Jordan using Industry 4.0, and they couldn't carry on in the project. But when this same question was asked to the Industry 4.0 project manager, he said that this project wasn't coping with their business models, and they were not aware of the fact that this is a nonprofit project. This question was aimed to discover what are the real challenges that made them leave the project as partners.

So, the first interview with *Ibtecar* was of around one hour. And the top management have answered the questions as the following. Please note that writing everything related to the question is part of the method to have a thematic analysis of the results as apart of applied thematic analysis.

- In Jordan the manufacturing is not using any type of related technologies to industry 4.0.
- The level of awareness is low in all the companies they have worked with, knowing that this company organizes free courses on IoT and CPS.
- And when they were asked about the challenges, they have focused on two important things. First, the lack of standards by three governmental bodies: TRC, custom and border protection and innovation ministry). At this point, they agreed that many products which can help in creating systems such as IoT can't enter the country without of permissions and control. Also using IoT technologies is hard to cope with the regulations of TRC where they have indicated that TRC has no real regulations which can help factories to adopt such technologies. Also, when it comes to the regulations of the innovation ministry of Jordan, they have no real implications in regards of any of the Industry 4.0 technologies.
- When they were asked about the energy issues, they mentioned that energy bills for the factories are high, causing around 20 factories to move to Saudi Arabia in the last 3 years before the covid crisis.
- Regarding the skills, they have agreed, all of them, that the analytical skills are the most important. Without it, the human power is not able to operate in Industry 4.0. One of the managers added to the analytical skills the importance of the interpersonal skills, by saying that, if you don't have enough interpersonal skills, you are not able to have a human-human relationship in the workplace. Also, they have said it is not important to have coding skills. It is enough to have one part of the team who is expert in coding, and they will be enough.
- They have tried to avoid answering what is really the project and why they have left it, but they answered that this project is only about building excellency. Its center is to

show Industry 4.0, in Jordan, to the companies, so they can increase the level of awareness.

- They have mentioned the importance of educational development in universities, and when they were asked about schools they said it is important as well, but they find universities more important.

The second interview was with the project manager of *Sam Engineering*, the project manager of Industry 4.0 in Jordan, and, at this time, is still the acting manager of this project.

- The manager of this project had also one hour for interview, during which the same questions as the previous interview were asked.
- The purpose of the project is to build an excellency center of industry 4.0 aided technologies, to show the factories in Jordan how it is possible to have it implemented.
- When asked about what the challenges of adopting these technologies are, he said that the real challenge is behind the TRC regulations. But he has mentioned that the real challenge is underlaying in the universities laps and the software they use for teaching, because it requires annual subscriptions which is expensive and they only buy the software but they can't afford the annual subscription, and it is expensive to have the licenses of these software, and he mentioned that he is proposing the creation of a platform to bring easier access of these technologies to the universities. And this way, they can use the power of CC, adopted in platforms like PaaS.
- He has also said that the project had investigated each company who applied to have the fund to adopt Industry 4.0; the results were that all the factories needed EPR systems which is a basic need even before having any real implications of Industry 4.0. Ten factories, which were eligible to it, received a fund of around 500,000 USD.
- When he was asked about skills necessary for the implementation of Industry 4.0, he mentioned that once he asked university professors about their opinion in this matter, and they answered that mathematics is the most important subject to assure the effectiveness of Industry 4.0, even in the case of a system crashing down. He focused on the fact that mathematics is the basic knowledge of robotics, and all the calculations are dependent on mathematics.

- When he was asked about the energy issues, he mentioned a project between the JAPM: the building of a solar farm to be used by all of them. This was then checked within the reports of the Amman Chamber of Industry, and reports on renewable energy were found.
- And when he was asked about the reality of I4.0 project in Jordan, he said that the companies in Jordan have not reached a maturity level to adopt these technologies. And he agrees with the thesis which examined this variable.(Shari & Altarazi, 2022)
- When the project manager was asked about how they know that the applicant is eligible, he answered thar, in fact, none of the ten factories is eligible, but they had to create this project. He added that the development of this project began in one of the oldest buildings in Amman. This was done by following the theory that if this building can comport these systems on a small scale, then they can have it in a bigger scale. One of the biggest concerns is about how TRC will regulate these technologies. And because of them Jordan will never have a real adoption of Industry 4.0.
- He explained how Industry 4.0 is more about software systems than hardware, therefore, the difficulties aggravate, when we consider that the internet infrastructure in Jordan is not yet good enough to support technologies.
- I4.0 Jo project manager added that cyber security is a major challenge facing manufacturing, ear from adopting I4.0 emerging technologies.

A study was done about the challenges in these factories, but it can’t be shared because of conflicts of interest. Once this project, which was started in 2020 is done, the results will be shared. In here we can conclude that there is no real adoption for Industry 4.0 technologies in Jordan now. The existence of online articles mentioning the adoption of Industry 4.0 is unreal. The main reason why this process has not yet started is related to its necessity of high financial investment, and the lack of trust on its financial return. The financial difficulties to adopt new technologies is not new but it reflects the awareness and maturity level in manufacturing investment environment in Jordan.

While searching for data to overcome the challenges of I4.0 adopting in Jordan, one researcher has been interviewed to reach for more information in regards of the adoption challenges and he stated that manufacturing organizations in Jordan misled him and even mislead I4.0 project manager in Jordan so they can have the eligibility to have the funds. This misleading was by telling the researchers that they have I4.0 related technologies in their manufacturing process where if fact they didn't. and trying to reach for the funding authority of I4.0 project in Jordan it was a limiting because, they didn't reply.

3.2 Quantitative analysis and results

In order to start this part of the thesis, it is necessary to revisit what was the study sample, and community; as a recap, it is also good to do a recap of quantitative analysis. Using the quantitative method approach of surveying, the top management of the Jordanian pharmaceutical industry was used as the study community. The survey was sent and collected between the time of October 1st and November 10th, to ensure the data validity of 40 days only; this method is well known and popular among social science studies (Wilson, 2014). The thesis sample consisted of Jordanian Association of Pharmaceutical Manufacturers (JAMP) which are 14 companies. (To access the study tool questionnaire, look *appendix number 3*.

- The dissertation survey was built based on the developed model that depends on the literature review (look study model table 1), and the interviews with the EU funded project Industry 4.0 managers in Jordan.
- The study tool (questionnaire) was tested by five managers from other industries, before it was posted and sent to the target sample. This was done to test its reliability, noted that those 5 were not included in the analysis or part of the study.
- The characteristics of the sample and questionnaire respondents are described in the analysis, using descriptive statistics. The "Statistical Package for Social Science" (SPSS.24) was used to analyze structural equation modeling and test the study hypotheses.
- Study population and sample of the thesis:

  210 questionnaires were obtained, and after the initial sorting of these questionnaires, 10 questionnaires were excluded due to their inadequacy for accuracy and reliability. Thus, 200 questionnaires were used in the statistical analysis process; it is also important to note that the five responses done by managers of other industries during the validity test were not included in the 210 questionnaires.

- The study population included human power at the senior management levels in Jordanian pharmaceutical companies, and to ensure the achievement of the objectives of the study, the study was carried out on the companies listed in The Jordanian Association of Pharmaceutical Manufacturers JAPM; numbering, 14 companies.
- The study sample was selected using the appropriate convenience sampling method, as an electronic questionnaire designed through Google forms was distributed and shared through social media and e-mail with workers at the supervisory and administrative levels in these companies.
- The statistical methods used in the quantitative analysis:

  To test the hypotheses of the study and achieve its objectives, the researcher conducted through the statistical package for social sciences SPSS appropriate statistical tests by employing the following statistical methods:

  g- Frequencies, percentages, arithmetic means, and standard deviations to extract the values of descriptive statistics.

  h- Exploratory factor analysis to detect structural validity in the questionnaire items.

  i- Cronbach alpha stability coefficient test to measure reliability.

  j- Normal distribution test to verify the normal distribution of data.

  k- Variance inflation factor test to ensure that there is no multi-correlation between the independent variables.

  l- Multiple linear regression analysis to test hypotheses: Where this test was conducted, after making sure that its statistical assumptions are met, that is, the presence of linearity and the normal distribution of the data, and therefore it can be performed because it is one of the parametric tests.

Validity

The validity of the study tool was confirmed through construct validity, as shown below:

The construct validity, which expresses the statistical validity of the questionnaire items, has been verified through the Exploratory Factor Analysis EFA test, which measures the validity of the items by knowing the level of item correlation on the factor or variable (Hair et al., 2010), and thus it can be said that to construct validity is an important measure that shows and interprets the statistical validity of the scale used in data collection. The main objective of the exploratory factor analysis is to verify and reveal the correlational strength between the items, which shows the extent of saturation of these items on the factor or variable and thus interpret it from a statistical point of view (Hair et al., 2014).

The following statistical measures were used when conducting the exploratory factor analysis:

1- Kaiser-Meyer-Olkin KMO test: This is to verify the adequacy of the sample size to conduct the test and that the statistically acceptable value must be higher than 0.5.

2- Factor loadings: where the factor loadings are considered the statistical indicator that measures the duration of the correlation and saturation of the items on the factor; the minimum threshold for accepting the item and considering it valid and valid for statistical analysis is 0.50, and that any item whose loading factors is less than 0.50 is excluded.

1- Exploratory factor analysis of the industry 4.0 adoption challenges items

Table 8 Exploratory factor analysis of the Industry 4.0 adoption challenges items

No	Item	Factor loading	KMO Test
	Upfront investment/cost		
1	I believe that the Lack of financial means is a challenge to implement Industry 4.0 in the pharma manufacturing in Jordan	0.667	0.762
2	Requirement of continuous training and education to upskill the work force to meet the requirement of industry 4.0 is costly	0.645	
3	Industry 4.0 emerging technologies requires huge Energy costs to operate in pharma manufacturing	0.715	
4	I believe that there is a lack of infrastructure means in terms of internet and energy in Jordan to adopt industry 4.0 technologies	0.632	
5	Smart manufacturing technologies have enough finance plans provided by the leading companies in the related fields	0.747	

6	I believe using renewable energy to operate smart factory technologies is feasible in term of energy costs	0.626	
Legislation and standards			
7	There is Lack of standards to regulate the communication methods of Industry 4.0 ex (IoT)	0.857	0.869
8	(Import /export) standards are not updated to comply with Industry 4.0 technologies in Jordan which makes it a challenge to adopt such technologies.	0.892	
9	I believe that laws and regulations in terms of cyber security are not enough to regulate the adoption of Industry 4.0 in the pharma manufacturing in Jordan.	0.860	
10	I believe that there is a lack of investment promotions standards in the government to attract FDI (forging direct investment) to adopt industry 4.0 technologies.	0.824	
11	Renewable energy solutions have lack of standards to be adopted in mass production in the pharmaceutical manufacturing in Jordan	0.831	
Management			
12	I think that there is a Lack of understanding of the strategic importance of Industry 4.0 in the management of pharma manufacturing in Jordan.	0.613	0.866
13	I believe that the management of pharma manufacturing in Jordan are more focused on operation at the expense of developing the company (ambidexterity)	0.831	
14	Awareness and Change Resistance at the top management level is challenging the adoption of industry 4.0 in pharma manufacturing.	0.723	
15	I believe the top-level management are more driven to short term profit compared to long term of adopting new technological means of smart factory	0.807	
16	Top management in the pharmaceutical sector in Jordan are collaborating to create energy plans	0.852	

17	There are enough regulations to drive the consumer behaviour based on their needs rather than the production strategies	0.864	
Risks of adopting			
18	I believe the Lack of data protection (cyber security) is a challenge to adopt industry 4.0 emerging technologies	0.768	0.871
19	Using Industry 4.0 emerging technologies will risk of Compatibility with the pharma Regulatory Affairs of FDA, EMA, and MENA standards.	0.833	
20	Using Industry 4.0 emerging technologies in the pharma manufacturing can affect Pharmaceutical continuous manufacturing system in case of system failure risk	0.776	
21	Adopting Industry 4.0 emerging technologies will increase the unemployment rate increasing risk	0.804	
22	I believe using simulation to create risk reduction scenario can help in mitigating unforeseen events in the pharma manufacturing in Jordan	0.881	
23	I believe that using Artificial intelligence in the quality control of medications can increase the health risk compared with humans.	0.712	
Work force (Operator 4.0)			
24	I believe that there is a Lack of qualified work force to operate Industry 4.0 in the pharma industry in Jordan	0.782	
25	There is Lack of employee readiness in terms of awareness and training.	0.600	
26	There is a Lack of understanding the relationship (human-machine) among the work force of pharma manufacturing in Jordan.	0.833	

27	I believe there is a change Resistance in the work force among the pharma manufacturing in Jordan.	0.835	0.894
28	having coding skills will be essential in operating Industry 4.0 technologies in the manufacturing	0.840	
29	I believe that the analytical skills are important to operate Industry 4.0 technologies and basic systems as well	0.770	

Source: Own calculation dissertation contribution

Table 8 refers to the exploratory factor analysis, to verify the validity of the clauses of the independent variables. As it was found that all KMO test values were greater than 0.50, this indicates that the sample size is sufficient to conduct the test; all factor loadings were greater than 0.50. It denotes the construct validity of the items of the independent variables.

2- Exploratory factor analysis of Adopting industry 4.0 emerging technologies in the pharmaceutical manufacturing in Jordan items

Table 9 Exploratory factor analysis of the Adopting industry 4.0 emerging technologies in the pharmaceutical manufacturing in Jordan items

No	Item	Factor loading	KMO Test
1	I believe that using Industry 4.0 emerging technologies in the pharmaceutical manufacturing in Jordan will increase the quality of the products and reduce the time.	0.810	0.894
2	I believe using digital twin and similar technologies will help the decision makers to have tackle complexity of the market	0.852	
3	Industry 4.0 adoption in the pharma manufacturing will increase the volatility, uncertainty, complexity, and ambiguity.	0.829	

4	Adoption of Industry 4.0 technologies such as block chain NFT in pharmaceutical manufacturing in Jordan will increase the customer satisfaction.	0.866	
5	Industry 4.0 emerging technologies adoption in the pharmaceutical manufacturing sector can play a huge role in the contingency plans in case of crises.	0.825	
6	I believe that adopting industry 4.0 in in the pharmaceutical manufacturing sector will increase the competitive advantage of Jordan in the global pharma market.	0.700	

Source: Own calculation

Table 9 summarizes the results of the exploratory factor analysis to verify the construct validity of the items of the dependent variable. As it was found that all KMO test values were greater than 0.50, this indicates that the sample size is sufficient to conduct the test, and all factor loadings were greater than 0.50. It denotes the construct validity of the items of the dependent variable.

Reliability of the study tool

The reliability *stability* of the study tool was verified by calculating the values of the Cronbach alpha coefficients for all the study items, where reliability is defined as "the extent of internal consistency between the items of the questionnaire, as the internal consistency between items indicates the presence of stability in their answers over time. The fixed and stable test gives the same results when applying the tests to the same group again.

The reliability values can be considered acceptable if the values of the Cronbach alpha coefficients (which measure the validity of the internal consistency) are greater than 0.70.

Table 10 Questionnaire reliability and Cronbach alpha values

Variable	Alpha Cronbach coefficient	No. of items
Upfront investment/cost	0.757	6
Legislation and standards	0.905	5
Management	0.872	6
Risks of adopting	0.881	6

work force (Operator 4.0)	0.872	6
Adopting industry 4.0 emerging technologies	0.896	6
Total No. of items	0.899	35

Source (Own calculation)

Through the results contained in 3.5, the reliability of the items used in the questionnaire is evident, as it was found that all Cronbach alpha values ranged between (0.757-0.905), and these values indicate the presence of stability and reliability in the items in the questionnaire, where all values were higher than 0.70. This was confirmed by (Hair et al., 2019).

Statistical Analysis of the quantitative tool

This chapter reviews all the statistical procedures that were used to achieve the objectives of the study, from descriptive statistical procedures to test the hypotheses of the study.

Descriptive statistics of the characteristics of the study sample

First: gender

Table 11 indicates the results of the descriptive census of the study sample according to the gender variable, where the number of males was 153, with a percentage of 76.5%, while the number of females was 47, with a percentage of 23.5%.

Table 11 Respondents' Gender

Variable		Frequency	Percentage
Gender	Male	153	76.5%
	Female	47	23.5%
Total		200	100%

Source: Own calculation

Second: age

Table (10) indicates the results of the descriptive census of the study sample according to the age variable, where most of the respondents, whose ages ranged between 41-50 years, were 69 with a rate of 34.5%; the number of respondents ranged between 30-40 years were 65 individuals, or 32.5%; the number of respondents whose age was less than 30 years was 42, or 21%. Finally, the number of respondents, whose ages ranged from 51 years or older, was 24, or 12%.

Table 12 Respondents' Age

Variable		**Frequency**	**Percentage**
Age	Less than 30 years	42	21%
	30-40 years	65	32.5%
	41-50 years	69	34.5%
	51 years and above	24	12%
Total		200	100%

Source: (Own calculation)

Third: education

The results in *Table 13* show the demographic characteristics of the study sample according to the education variable, as it was found that most of the respondents had a bachelor's degree, with 140 individuals, or 70%. In contrast, the number of holders of postgraduate degrees reached 57, or 28.5%. Finally, the number of respondents holding diplomas was less than 3, at a rate of 1.5%.

Table 13 Respondents' Education

Variable		**Frequency**	**Percentage**
Education	Diploma or less	3	1.5%
	Bachelor's degree	140	70%
	Postgraduate degree	57	28.5%
Total		200	100%

Source: (Own calculation)

Fourth: years of experience

Table 14 shows the results of the descriptive statistics of distribution of the study sample according to the years of experience, where most of the respondents whose years of experience ranged between 5-10 years were 95 individuals, or 47.5%; the number of respondents whose years of experience were between 11-15 years reached 59 individuals, or 29.5%; and the number of respondents whose years of experience were less than 5 years was 30 individuals, or 15%. Finally, the number of respondents whose years of experience were 16 years, or more was 16 individuals, or 8%.

Table 14 Respondents' years of experience

Variable		Frequency	Percentage
Respondents' years of experience	Less than 5 years	30	15%
	5-10 years	95	47.5%
	11-15 years	59	29.5%
	16 years and above	16	8%
Total		200	100%

Source: (Own calculation)

Descriptive statistics of the study variables: Descriptive statistics of Industry 4.0 adoption challenges

Descriptive statistics for upfront investment/cost

Table (15) refers to the descriptive statistics of the Upfront investment/cost items, where the overall mean value was of 3.92 with a standard deviation of 0.557. The highest paragraph, according to the mean values, was Paragraph No. 1, with a mean value of 4.27 and a standard deviation of 0.753; the lowest paragraph with respect to mean values was Paragraph No. 4, with a mean value of 3.46 and a standard deviation value of 0.929. It can be said, according to the respondents of the study, that the lack of financial resources could play a major role in the application of industry 4.0, and that these applications need large financial resources and investments at a high level It also needs great management support, especially for research and development within these companies. In addition, the lack of training and continuous learning may limit the application of Industry 4.0, as to meet the requirements of applying this technology requires large organizational resources that are not found in companies that do not focus on their human resources and thus can limit the application of Industry 4.0. Also, according to the respondents, the infrastructure in Jordan still needs greater development, especially the Internet infrastructure. This may associate the adoption of Industry 4.0 with great challenges that may prevent its adoption in the future, and therefore more attention should be paid to the technical infrastructure.

Table 15 Descriptive statistics of the upfront investment/cost items

No	Items	Mean Value	Standard Deviation
1	I believe that the Lack of financial means is a challenge to implement Industry 4.0 in the pharma manufacturing in Jordan	4.27	0.753
2	Requirement of continuous training and education to upskill the work force to meet the requirement of industry 4.0 is costly	4.12	0.747
3	Industry 4.0 emerging technologies requires huge Energy costs to operate in pharma manufacturing	3.82	0.837
4	I believe that there is a lack of infrastructure means in terms of internet and energy in Jordan to adopt industry 4.0 technologies	3.46	0.929
5	Smart manufacturing technologies have enough finance plans provided by the leading companies in the related fields	3.81	0.925

6	I believe using renewable energy to operate smart factory technologies is feasible in terms of energy costs	4.09	0.769
Overall mean		3.92	0.557

Source: (Own calculation)

Second: the descriptive statistics of the Legislation and standards paragraphs

Table 15 summarizes the results of the descriptive statistics of the Legislation and standards items, as it was found that the overall mean value was of 3.72, with a standard deviation of 0.739. The highest item according to mean values was *Paragraph No. 10*, with a mean value of 3.88 and a standard deviation of 0.774, and the lowest item with respect to mean values was *Paragraph No. 8,* with a mean value of 3.61 and a standard deviation value of 0.917. It is clear from the responses that laws and standards in Jordan suffer from many problems in the case of adopting new technologies, as respondents to the study confirmed that Jordan suffers from major problems in adopting laws and regulations supporting cybersecurity and regulating Industry 4.0, and this leads to limiting the implementation of this technology in the work. In addition, the laws related to importation and exportation in Jordan are not compatible. According to the respondents, with the fourth industrial revolution, as there are many restrictions on adopting this technology, these laws may lead to limiting foreign investment in Jordan and thus delay the introduction of industry 4.0 technologies. This will lead to the non-adoption of these technologies by pharmaceutical companies in Jordan. Also, the study respondents emphasized the lack of sufficient seriousness, on the part of the Jordanian government, in adopting renewable energy solutions, necessary for Industry 4.0 applications, in various local industries, especially the pharmaceutical industries, decreasing the possibility of adoption of these technologies at work.

Table 16 Descriptive statistics of the Legislation and standards items

No	Items	Mean Value	Standard Deviation
7	There is Lack of standards to regulate the communication methods of Industry 4.0 ex (IoT)	3.74	0.927
8	(Import /export) standards are not updated to comply with Industry 4.0 technologies in Jordan which makes it a challenge to adopt such technologies.	3.61	0.917

9	I believe that laws and regulations in terms of cyber security are not enough to regulate the adoption of Industry 4.0 in the pharma manufacturing in Jordan.	3.68	0.807
10	I believe that there is a lack of investment promotions standards in the government to attract FDI (forging direct investment) to adopt industry 4.0 technologies.	3.88	0.774
11	Renewable energy solutions have lack of standards to be adopted in mass production in the pharmaceutical manufacturing in Jordan	3.69	0.909
Overall mean		3.72	0.739

Source: (Own calculation)

Third: the descriptive statistics of management items

Table 17 summarizes the results of the descriptive statistics of management items. It was found that the overall mean value was of 3.74 with a standard deviation of 0.656. The highest item according to the mean values was item *No. 14*, with a mean value of 4.01 and a standard deviation of 0.687; the lowest item in mean values was item No. 13, with a mean value of 3.34 and a standard deviation value of 0.964. It is clear from the results of the respondents that there is a lack of administrative awareness of the importance of Industry 4.0, as management in Jordanian pharmaceutical manufacturing companies focuses only on using traditional methods of work without having a strategic direction, thus limiting the use of Industry 4.0 in various manufacturing activities. There is a clear focus by Jordanian pharmaceutical manufacturing companies on the use of traditional and usual methods at the expense of creativity, which enhances the use of operational and traditional technology, thus not relying on industry 4.0, as there is high resistance to change when managing in this field. This leads to a lack of investment and adoption of such technology. According to many management theories, the administration that maintains environmental stability tries to tend to short profit compared to long profit, and this makes the administration keener to adopt traditional technology more.

Table 17): Descriptive statistics of the management items

No	Items	Mean Value	Standard Deviation

12	I think that there is a Lack of understanding of the strategic importance of Industry 4.0 in the management of pharma manufacturing in Jordan.	3.74	0.875
13	I believe that the management of pharma manufacturing in Jordan are more focused on operation at the expense of developing the company (ambidexterity)	3.34	0.964
14	Awareness and Change Resistance at the top management level is challenging the adoption of industry 4.0 in pharma manufacturing.	4.01	0.687
15	I believe the top-level management are more driven to short term profit compared to long term of adopting new technological means of smart factory	3.75	0.843
16	Top management in the pharmaceutical sector in Jordan are collaborating to create energy plans	3.84	0.798
17	There are enough regulations to drive the consumer behaviour based on their needs rather than the production strategies	3.73	0.856
Overall mean		3.74	0.656

Source: (Own calculation)

Fourth: the descriptive statistics of the items Risks of adopting

Table 18 summarizes the results of the descriptive statistic for the Risks of Adopting items, as it was found that the overall mean value was of 3.78 with a standard deviation of 0.692. The highest item according to the mean values was item *No. 22*, with a mean value of 3.94 and a standard deviation of 0.806; the lowest item in respect to mean values was item *No. 20*, with a mean value of 3.64 and a standard deviation value of 1.00. It is noted through the responses that there are many potential risks that may limit the use of industry 4.0 in pharmaceutical companies in Jordan, mostly due to the lack of protection and lack of data protection. These main factors limit the use of industry 4.0, which relies heavily on big data and analysis, which leads to non-reliance on these techniques. In addition, the respondents of the study believe that there are many operational risks that may arise by relying on industry 4.0, such as stopping production lines from working or increasing technical malfunctions in electronic systems. This will damage work within factories, so the respondents believe that there are many factors which may limit pharmaceutical companies' use of Industry 4.0

Table 18 Descriptive statistics of the Risks of adopting items

No	Items	Mean Value	Standard Deviation
18	I believe the Lack of data protection (cyber security) is a challenge to adopt industry 4.0 emerging technologies	3.74	0.904
19	Using Industry 4.0 emerging technologies will risk of Compatibility with the pharma Regulatory Affairs of FDA, EMA, and MENA standards.	3.83	0.801
20	Using Industry 4.0 emerging technologies in the pharma manufacturing can affect Pharmaceutical continuous manufacturing system in case of system failure risk	3.64	1.00
21	Adopting Industry 4.0 emerging technologies will increase the unemployment rate increasing risk	3.76	0.856
22	I believe using simulation to create risk reduction scenario can help in mitigating unforeseen events in the pharma manufacturing in Jordan	3.94	0.806
23	I believe that using Artificial intelligence in the quality control of medications can increase the health risk compared with humans.	3.79	0.856
Overall mean		3.78	0.692

Source: (Own calculation)

Fifth: Descriptive statistics of workforce items (Operator 4.0)

Table 19 refers to the results of the descriptive statistics of workforce (Operator 4.0) items, as it was found that the overall mean value was of 3.64 with a standard deviation of 0.724. The highest item according to the mean values was item *No. 29*, with a mean value of 3.95 and a standard deviation of 0.811; the lowest item mean value was item *No. 26*, with a mean value of 3.54 and a standard deviation value of (0.955). According to the responses, it can be said that the application of industry 4.0 technologies and principles in the pharmaceutical industry in Jordan is extremely difficult due to the lack of human skills required to operate such technologies, as the respondents see that there is a significant shortage of manpower qualified to operate Industry 4.0 in the pharmaceutical industry. This will limit the use of industry 4.0 in these companies. Also, these companies suffer from a lack of human resources ready to use Industry 4.0, so it is important to work on training those working in these companies to use modern systems related to Industry 4.0.

Table 19 Descriptive statistics of the work force (Operator 4.0) items

No	Items	Mean Value	Standard Deviation
24	I believe that there is a Lack of qualified work force to operate Industry 4.0 in the pharma industry in Jordan	3.82	0.884
25	There is Lack of employee readiness in terms of awareness and training.	3.80	0.757
26	There is a Lack of understanding the relationship (human-machine) among the work force of pharma manufacturing in Jordan.	3.54	0.955
27	I believe there is a change Resistance in the work force among the pharma manufacturing in Jordan.	3.66	0.947
28	having coding skills will be essential in operating Industry 4.0 technologies in the manufacturing	3.39	1.00
29	I believe that the analytical skills are important to operate Industry 4.0 technologies and basic systems as well	3.95	0.881
Overall mean		3.64	0.724

Source: (Own calculation)

Descriptive statistics of the variables of adopting industry 4.0 emerging technologies

Table 20 refers to the results of the descriptive statistics for adopting industry 4.0 emerging technologies, as it was found that the overall mean value was of 2.18 with a standard deviation of 0.629. The highest paragraph according to the mean values was item *No. 3*, with a mean value of 2.35 and a standard deviation of 0.793. The lowest item for mean values was item *No. 5,* with a mean value of 1.97 and a standard deviation value of 0.668. The study respondents agree that they are not sufficiently aware of the importance of Industry 4.0 and its uses in Jordanian pharmaceutical companies. As they confirmed, they are not sure of the importance of these technologies in improving quality. Also, these respondents believe that these technologies may not lead to improvement of various decision-making proceses, and, therefore, according to the respondents, these technologies may not play a role in enhancing the activities of companies, which leads to the failure to achieve new competitive advantages, according to their opinion.

Table 20Descriptive statistics of the adopting industry 4.0 emerging technologies items

No	Items	Mean Value	Standard Deviation
1	I believe that using Industry 4.0 emerging technologies in the pharmaceutical manufacturing in Jordan will increase the quality of the products and reduce the time.	2.06	0.737
2	I believe using digital twin and similar technologies will help the decision makers to have tackle complexity of the market	2.19	0.773
3	Industry 4.0 adoption in the pharma manufacturing will increase the volatility, uncertainty, complexity, and ambiguity.	2.35	0.793
4	Adoption of Industry 4.0 technologies such as block chain NFT in pharmaceutical manufacturing in Jordan will increase the customer satisfaction.	2.27	0.838
5	Industry 4.0 emerging technologies adoption in the pharmaceutical manufacturing sector can play a huge role in the contingency plans in case of crises.	1.97	0.668
6	I believe that adopting industry 4.0 in in the pharmaceutical manufacturing sector will increase the competitive advantage of Jordan in the global pharma market.	2.29	0.830
Overall mean		2.18	0.629

Source: (Own calculation)

Tests of the suitability of study data to test hypotheses

Hypothesis testing was carried out through multiple linear regression analysis, and since these tests need to provide many statistical conditions and assumptions before getting applied, many statistical tests have been conducted to ensure that the needed conditions are met.

The tests that were conducted to verify the suitability of the study data for testing the hypotheses included:

- The normal distribution tests.

- Multicollinearity test between the independent variables.

Normal distribution test

The distribution of the study data was confirmed using normal distribution by extracting the values of the skewness and kurtosis coefficients on the slop of normal distribution using Spss v.24 software. According to many statistical references such as (Hair et al., 2014), the values of the absolute skewness coefficients should not exceed 1 and the values of the absolute kurtosis coefficients should not exceed 3. *Table 21* shows the results of the normal distribution test. It is clear from the results presented in *Table 21* that all the values of skewness and kurtosis were within the acceptable statistical range, and this confirms that the data of the study are distributed normally.

Table 21 The normal distribution test

Variables	Skewness coefficient	Kurtosis coefficient
Upfront investment/cost	-0.434	0.980
Legislation and standards	-0.511	0.098
Management	-0.217	-0.034
Risks of adopting	-0.251	-0.330
Work force (Operator 4.0)	-0.421	0.360
Adopting industry 4.0 emerging technologies	0.186	-0.035

Source: (Own calculation)

Multicollinearity test

This test is important to ensure that there are no high correlations between the independent variables that lead to a false estimate of the regression equation. Therefore, if this test is not well managed, the results of the multiple linear regression analysis tests will be inaccurate and lead to inconsistent results.

This test was conducted by calculating the values of the Variance inflation factor VIF, and the allowable variation coefficients 1/VIF. As results, the values of VIF should be less than 10 and the values of 1/VIF should be higher than 0.10. *Table 19* shows the results of the tests, as it is clear from the results presented in *Tables 6-12* that there are no problems associated with multicollinearity. All values were statistically acceptable, and therefore a multiple linear regression test can be performed.

Table 22 Results of Variance Inflation Factor and Tolerance

Variables	VIF	Tolerance
Upfront investment/cost	0.518	1.930
Legislation and standards	0.297	3.363
Management	0.245	4.074
Risks of adopting	0.220	4.536
work force (Operator 4.0)	0.290	3.443

Source: (Own calculation)

Hypothesis Testing

To achieve the objectives of the study, the hypotheses were tested by using multiple linear regression analysis, as shown in *Table 23*, with values of less than 0.05. This indicates the validity of the model to conduct the analysis. The value of the multiple correlation coefficient R was calculated between all the independent variables and the dependent variable, and the value was -0.858. This value indicates that there is a strong negative relationship between the independent variables and the dependent variable. To find out the predictive ability of the independent variables, the value of the coefficient of determination R^2 was calculated; the value was of 0.737. This value indicates that 73.7% of the variation in the dependent variable is caused by the independent variables combined. the results of the statistical tests that was applied to accept or reject the study hypothesis can be seen below in *Table 23*, testing, as it was found that there were negative effects of all independent variables on the dependent variable, and all effects were statistically significant.

<u>1- The impact of upfront investment/cost on adopting industry 4.0 emerging technologies:</u>

The value of beta was -0.201, and this value indicates that there is a negative impact of upfront investment/cost on Adopting industry 4.0 emerging technologies. The value of t was -3.475, and the value of the significance level was 0.001, which is less than the level of statistical significance at the level of 0.05. Therefore, the null hypothesis can be rejected, and the alternative hypothesis accepted, which states that "industry 4.0 Upfront investment/cost has a negative direct effect on adopting the I4.0 in the pharmaceutical manufacturing in Jordan".

<u>2- The impact of Legislation and Standards on Adopting Industry 4.0 Emerging Technologies:</u>

The value of beta was -0.132, and this value indicates that there is a negative effect of legislation and standards on Adopting industry 4.0 emerging technologies. The value of t was -2.305, and the value of the significance level was 0.022, which is less than the level of statistical significance, of 0.05. Thus, the null hypothesis can be rejected, and the alternative hypothesis accepted, which states: "Legislations and standards in Jordan have a negative effect on adopting Industry 4.0 in the pharmaceutical manufacturing industry in Jordan."

<u>3- The impact of management on adopting industry 4.0 emerging technologies:</u>

The value of beta was -0.150, and this value indicates that there is a negative impact of Management on Adopting industry 4.0 emerging technologies. The value of t was -2.103, and the value of the significance level was of 0.037), which is less than the level of statistical significance, of 0.05). Thus, the null hypothesis can be rejected, and the alternative hypothesis accepted, which states "Pharmaceutical manufacturing management decisions have a negative impact on adopting Industry 4.0 emerging technologies in the manufacturing in Jordan."

<u>4- The impact of risks of adopting-on-adopting industry 4.0 emerging technologies:</u>

The value of beta was -0.302, and this value indicates that there is a negative impact of risks on adopting-on-adopting Industry 4.0 emerging technologies. The value of t was -4.230, and the value of the significance level was 0.000, which is less than the level of statistical significance at the level of 0.05. Thus, the null hypothesis can be rejected, and the alternative hypothesis can be accepted, which states: "adopting Industry 4.0 in the pharmaceutical manufacturing in Jordan is more likely to increase the risk and leave a negative impact on adopting this technology.”

5- The impact of the workforce (Operator 4.0) on adopting industry 4.0 emerging technologies:

The value of beta was -0.132, and this value indicates that there is a negative effect of the workforce (Operator 4.0) on Adopting industry 4.0 emerging technologies. The t value was of -2.184, and the value of the significance level was 0.030, which is less than the level of statistical significance, of 0.05. Thus, it is possible to reject the null hypothesis and accept the alternative hypothesis, which states: "The workforce readiness to meet the operator 4.0 requirements will decrease the ability to adopt Industry 4.0 in pharmaceutical manufacturing in Jordan."

Table 23 Hypothesis testing

Independent variables	Dependent variable	R	R^2	F	Sig (F)	Beta	Std. Error	t-values	Sig	Result
Upfront investment/cost	Adopting industry 4.0 emerging technologies	0.858	0.737	108.44	0.000	-0.201	0.058	-3.475	0.001	Significant
Legislation and standards						-0.132	0.057	-2.305	0.022	Significant
Management						-0.150	0.071	-2.103	0.037	Significant
Risks of adopting						-0.302	0.071	-4.230	0.000	Significant
work force (Operator 4.0)						-0.132	0.061	-2.184	0.030	Significant
Calculated t = 1.96										

Source: (Own calculation)

The findings of the research emphasize the significance of tackling a number of issues that prevent Industry 4.0 implementation in Jordan's pharmaceutical manufacturing sector. One of these elements is initial investment or cost, which the study revealed to have a detrimental effect on Industry 4.0 adoption. This implies that decision-makers and industry stakeholders should think about ways to lessen the cost of implementing Industry 4.0 technology, such as by offering financial incentives or support.

Similar to this, the study discovered that regulations and standards, managerial choices, risks, and labor readiness are all substantial roadblocks to the implementation of Industry 4.0 in Jordan's pharmaceutical manufacturing sector. integrating regulations to promote adherence to industry standards, enhancing management procedures, lowering the risks involved with integrating new technology, and investing in workforce development and training to fulfill Industry 4.0 requirements are some ways to address these challenges.

It is important to note that the results of this study could have wider ramifications for other markets and nations who are also having trouble implementing Industry 4.0. In order to achieve the benefits of higher productivity, efficiency, and competitiveness that come with Industry 4.0 adoption, policymakers and industry stakeholders can use the findings from this study to guide their actions in this regard.

The study's findings demonstrate the importance of addressing numerous obstacles to Industry 4.0 adoption in Jordan's pharmaceutical manufacturing sector by policymakers, managers, and other stakeholders. By removing these obstacles, the adoption of new technology may be facilitated, productivity can be increased, and the economy of the nation can expand and develop.

Quantitative analysis results discussion

The study reached a variety of results, the most important of which were:

1- The results of the study concluded that there is a negative and statistically significant upfront investment/cost effect on Adopting Industry 4.0 emerging technologies, as it is possible that the lack of investments in Industry 4.0 and the lack of interest in creating an infrastructure based on this industry may play a role, as emphasized (Walendowski et al., 2016a). This lack of investment can play a negative correlation with the adoption of industry 4.0 technology by manufacturing companies, and this was agreed upon by many studies such as (Kagermann, Wahlster, et al., 2013a; Luthra & Mangla, 2018b).

Lack of financing and lack of investment can delay the adoption of emerging industry 4.0-related technologies such as big data analytics, Internet of Things, cloud computing and other. It can be said, according to the results of the questionnaires, that the lack of financial resources could play a major role in the application of Industry 4.0, that these applications need large financial resources and investments at a high level, and great management support, especially for research and development within these companies. In addition, the lack of training and continuous learning may limit the application of Industry 4.0, as meeting the requirements of applying this technology requires large organizational resources that are not found in companies that do not focus on their human resources and thus can limit the application of Industry 4.0. Also, according to the respondents, the infrastructure in Jordan still needs greater development, especially the Internet infrastructure, and this may bring the adoption of Industry 4.0 great challenges that may prevent its adoption in the future; therefore, more attention should be paid to the technical infrastructure.

2- The results of the study concluded that legislation and standards have a negative impact on Adopting industry 4.0 emerging technologies. It is necessary to set standard requirements that promote and regulate these technologies, in addition to that technologies such as the Internet of Things and big data analytics need codes of conduct and a guide for workers in order to use it in a proper and ethical manner, the results of the study agreed with a group of studies such as (Kagermann, Wahlster, et al., 2013a; Yu et al., 2015)

It is clear from the responses that laws and standards in Jordan suffer from many problems in adopting new technologies; as it was shown by the questionnaires, Jordan suffers from major problems in adopting laws and regulations supporting cybersecurity and regulating Industry 4.0, and this leads to limiting the adoption of this technology in work.

In addition, the laws related to importation and exportation in Jordan are not compatible, according to the respondents, with the Fourth Industrial Revolution; as there are many restrictions on adopting this technology, laws may lead to limiting foreign investment and thus delay the introduction of industry 4.0 technologies to Jordan.

Also, the study respondents emphasized the lack of sufficient seriousness on the part of the Jordanian government to adopt renewable energy solutions and use them with industry 4.0 applications in various local industries.

3- The results of the study concluded that management has a negative impact on Adopting industry 4.0 emerging technologies, as the lack of senior management support for digital transformation initiatives might also help to achieve the lowest possible organizational capacity, and this will negatively affect the adoption of Industry 4.0.

The results of the study agreed with the study of (Geissbauer et al., 2016; Haug et al., 2011; Stentoft et al., 2017).

It is clear from the results of the questionnaires that there is a lack of administrative awareness of the importance of Industry 4.0, as management in Jordanian pharmaceutical manufacturing companies focuses only on using traditional methods of work without having a strategic direction to use this technology in work and thus limiting the use of Industry 4.0. There is a clear focus on the use of Jordanian pharmaceutical manufacturing companies on traditional and usual methods at the expense of creativity-this enhances the use of operational and traditional technology, and thus not relying on Industry 4.0, as there is high resistance to change in this field. As result, there is a strong lack of investment and adoption of such technologies. According to many management theories, the administration that maintains environmental stability tries to tend to short profit compared to long profit, which makes the administration keener to adopt traditional technology more.

4- The results of the study confirmed that there is a negative impact of the Workforce on adopting Industry 4.0 emerging technologies, as human resources and workers who are not qualified enough, which can lead to their resistance to this technology. Workers with low skills will not be able to handle this technology optimally, and this has been confirmed by many studies, such as (Probst et al., 2017; Haung et al., 2011; Lee et al., 2007).

Companies suffer from a lack of human resources ready to use Industry 4.0, so it is important to train the workforce in these companies to use modern systems related to Industry 4.0.

5- The results of the study concluded that there is a negative impact of risks of adopting-on-Adopting industry 4.0 emerging technologies, as companies that do not tend to take risks and are afraid of spending, and investing money in projects with new technology may exclude adoption strategies for this technology. This leads to a negative impact on Adopting industry 4.0 emerging technologies. The results of the study agreed with the study of (Probst et al., 2017; Shamim et al., 2016; Walendowski et al., 2016b, 2016a)

It is noted through the responses that there are many potential risks that may limit the use of Industry 4.0 in pharmaceutical companies in Jordan, as the respondents in this thesis believe that the lack of cyber protection and lack of data protection will limit the use of Industry 4.0, which relies heavily on big data and analyzes, which leads to non-reliance on these techniques.

The respondents of the study believe that there are many operational risks that may arise by relying on Industry 4.0, such as stopping production lines from working or increasing technical malfunctions in electronic systems, and this will lead to failure of work within factories.

4. Study results, Recommendations, and Conclusion

4.1 Conclusion

Industry 4.0, or even more advanced manufacturing activities, are always signs of newer times that bring many opportunities and challenges at the same time. What makes the difference between an opportunity and a challenge is the way that they are handled. In the first place there are drivers that steer the wheel of this technology's integration. This integration technology wheel is the key driver of the world order. In each period, the world order changed due to wars, natural or man-made disasters. These changes are the pushing force of that wheel. The results of the world order change can be seen in the geopolitical maps of the world. The aftermath of these drivers and world order changes over history have accumulated advanced knowledge and disasters to handle and learn from. Climate change, overpopulation and food security are those top debated issues or man-made disasters. Those challenges of our world must be faced so we can assure the safe existence of humankind on the Earth. Before the First Industrial Revolution, humankind started the pursuit of more land to have more resources. More resources mean more land for agricultural purposes. For sure, gold and silver were fever at all periods in human history, but it is absolutely useless in times of hunger, and they alone can't provide food security. At the dawn of the first industrial revolution, another natural source was there to start another race between nations. Steam engine was not the first thermal energy option which, historically, had implications on human life through the years, it was believed that even the Egypt Hyksos had a form of thermal energy application. But at the time of steam engine transportation became easier than ever. Steam engines made oil one of the resources that nations started to scout for; their interests were in lumber. Then new perspectives towards economic relations and exchanges, and the old commercial trade routes came to bring changes in what people knew possibilities of maintaining commercial transactions and distance between social groups. As mentioned in the literature, these changes escalated to take us to the time of merging knowledge. Thus, the world order has changed over time with these inventions. 2022 we have reached a new technological advancement. This knowledge is what some call the digitalized world order.

The power of new communication methods using internet technologies and satellite internet connection is called the 5th generation of telecommunication. It is the power key of time, with the use of AI. In here, we can realize that human beings must adjust to these new advanced technologies. Here, the thesis took this case to seize all the related documents that could be found online using the scientific web-based search engines (Scopus database). All the answers related to this study case were analyzed, which resulted in a view of most important skills and competencies for adopting the Fourth Industrial Revolution. In that study, it was also considered what kind of role COVID-19 had to push and accelerate the use of these technologies. Also, that study was used to see what the level of awareness regarding these technologies among High-Tec organizations employees is, to have a result of two important points in that topic. The first point is that people are not familiar with the concept of Industry 4.0, but if we explain this concept and/or ask about the technologies related to it, rather the name of it, we can see more positive feedback on the awareness level. The second thing is that even with the explanations we still have low awareness. This means that the training programs of the high tec companies, which mainly provide outsourcing services to other organizations, actually lack "*higher-quality*" training programs and a high qualified work force in regards of Industry 4.0 skills and competencies. It doesn't mean that the current quality of the company is low, but that it is not high enough to meet the necessities of Industry 4.0 and qualify a worker as an Operator 4.0. Here, the study could confirm what are the best skills and competencies model that need to be adopted in the training of work force. Also by conducting another research, as a conference, that aimed to highlight the use I4.0 technologies in disasters management by using CC and Big data to create a distance learning to mitigate covid-19 crisis, not only in Jordan but in the whole world. This research was done to see how the schoolteachers without training could use CC and Bigdata in the distance learning with school students. The challenge was not only facing schoolteachers but also the students and their families in Jordan during COVID-19. Yes, indeed this could be the solution of overcrowded schools but at the same time it could affect the interpersonal and personal skills of the students which can leave an impressive aftermath on the primary school students in terms of mental health and physical inactivity, which are health risk factors on adults and children. We could see in this research that the use of computer is challenging many families in Jordan who are affected by the economic impacts that arose in the last decade in Jordan and other countries, after the economic crisis of 2008.

Talking about the new advanced technologies can't be done without the use of AI and computer research techniques. This study used many open AI software to reach for all the information included in the secondary data part of this research and related to the research's main topics. Involving the computer advanced search and using these methods led the study to acknowledge that AI became a powerful and advanced technology in terms of Machine learning algorithms. ML algorithms can be classified into three major groups: supervised, unsupervised and reinforcement learning.

Using ML algorithms and connect it on the cloud to analyze and classify the information in the work place then transfer these data to imagery can be displayed using AR can achieve the aim of Operator 4.0 which is human workforce aided by the computer for flowless manufacturing and maintenance experience (Fantini et al., 2020; Kaasinen et al., 2020; Longo et al., 2017; Roldán et al., 2019; Romero et al., 2016, 2017; Ruppert et al., 2018; Scheffer et al., 2021; Segura et al., 2020). If we combine the abilities of I4.0 and operator 4.0 it can be the only way that humans can surpass the machine. But still the question would be reviewed in two main scenarios, both very important to level the advances and the different approaches to the use and necessity of AI. The first one would be what if the machine surpassed the human in terms of capabilities to perform tasks?

And the second scenario could be what if the system crashed and the Operator 4.0 can't perform tasks in basic needs processing?

Regarding both of these scenarios, the study had to investigate the questions by asking people who have more experience in these felids in Jordan and in Hungary. This process was represented and revisited in the *Challenges of Skills and Competencies in Industry 4.0* part of the study, as well as in the interview with the project managers of I4.0JO. Also, this research project had the chance to explore the opinion of an expert in nano semiconductors manufacturing and quantum physics specialist. And all of them were asked the same question which was the following: what are the skills and competencies that human workforce needs the most to cope with when we consider the labor market requirements? And the second question in this regard was: what are the set or sets of skills and competencies that humans need in order to maintain a good and sustainable operation of the I4.0 environment, while, at the same time, be able to solve the problem and think of a solution if the system goes off because of an unfortunate event, like a disaster or energy issues.

And to make this question clearer for the interview, they have been told to choose between the most important skill sets, one strong enough to fits both scenarios. Those sets were the same in the skills and competencies part of the study. First of all, they told me to go further into Construction, pharma, food and beverages, and automobile industry because those are the industries that uses advanced technologies more often and with bigger necessity, and they have the biggest share of GDP not only in Jordan but in the whole world. Then they added that they believe, based on their particle experience, of using these systems in manufacturing in that human can't produce even a single nano semiconductor processor without using robots. But still the creation of these robots must go through human operators and the maintenance of these robots is done by humans. Also, humans can understand the customer issues better than any computer or AI. This is related to the analytical skills and interpersonal skills, as most of them agreed on that the two most important skill sets were the following which fit the two scenarios at the same time Adopting I4.0 and disaster mitigation:

- Social/Interpersonal (intercultural skills, language skills, communication skills, networking skills, teamwork, ability to transfer knowledge, leadership skills),
- Methodological (creativity, research skills, problem-solving, conflict solving, decision making).

And if the system goes down, they believe that most human operators can't perform tasks in manufacturing. When I have asked the people who manage the industry 4.0 project in Jordan about what skills are a must in both cases of a system crash or in the case of AI and CPS aided manufacturing, they have mentioned that the analytical skills are the most important in terms of adopting challenges and the interpersonal skills can always be the solution to have a better decision-making process.

In here we could see how important the personal and interpersonal skills are for humans to be in the center of this industry. However, these skills are impacted by the technological and digitalized world order we raise our children in. This is one of the recommended topics that this study is suggesting that it needs further studies This is one of the topics recommended by this study for further investigation; it is necessary to look deeper into the matter in other to come to a reliable conclusion about how the impacts of the digitalized world changes society. It is also necessary to consider that this investigation is under a scenario constantly changing and bringing forward new conclusions. Another main issue is the continuous production of pharmaceutical products, which is necessary worldwide. From this point and recollecting previous studies, it is clear that further researches on pharmaceutical manufacturing should be done.

In Germany, United States, and China, we can see the overcoming of the challenges of adopting Industry 4.0 in the manufacturing, not only into smart factories but rather smart cities. Smart cities are meant to be more headed to solve the crises of overpopulation, climate change and food security. But in Jordan the case is way too different in terms of technology and even sustainability. Without the use of Industry 4.0 emerging technologies, the unemployment rate is 50% in the youth, while in Germany population is declining. In these terms, the two countries can't be compared, but we can see what challenges were met in developed countries in the process of implementation of Industry 4.0 and consider them as driver to adopt. This step was taken by the EU funded projects for innovation to help Jordan in adopting Industry 4.0.

In this matter this thesis took a turn to have a new scientific result in regard to these technologies adoption in Jordan, based on the recommendation of previous studies, and expert's recommendation. Adopting Industry 4.0 in the pharmaceutical manufacturing in Jordan considered as the most advanced sector of the Jordanian economy in technology, it was found that there are 155 companies producing pharma products for humans and animals. Only 14 of 155 companies are included in the pharma manufacturing association that gathered the top advanced companies that complies with the Pharma Regulatory Affairs of MEANA area, EU and FDA. This association was studied using a questionnaire as data collection instrument, and only the challenges were discussed during the conduction of this research, because previous studies have been done proving that there is no real implementation of Industry 4.0 in Jordan manufacturing. All the alternative hypotheses of the study were accepted which confirm the theories of the project about the challenges. Many things were revealed in this project which are considered new in the academic studies. Also, this study is considered as KPI key performance indicator and this is considered as novelty. Human workforce in Jordan lacks skills and competencies, while the skilled work force has been migrating to the gulf countries since the beginning of 1900's, which leaves Jordan with many challenges to improve the economy even more so to start the process of adopting Industry 4.0 applications. The internet infrastructure and the energy issue, extent to the fact of geopolitical effects, are the biggest challenging parts of adopting real manufacturing practices. Adopting atomic energy and even the overpopulation caused by the war around Jordan is threatening the whole country in terms of water security.

4.2 Dissertation novelty

This thesis took different approaches to reach to the core information of the topics, and therefore, new results were generated. It is more likely that these results are known but no documents have shared these results in the academic level.

- The study found that the higher citation of a document is not related to the core science of the document, and, after an investigation of why is that, it turns out to be the name of the author and the institution they represent is the reason behind too many citations. And this was one of the reasons to exclude some documents from the research which could be found on both Scopus and web of science. Also, an element which is not a new scientific result but is worth of mentioning is that using google scholar to search for academy and peer reviewed sources is less likely to be useful because of the algorithm google is using which leads to the most connected content to the search keywords. other databases like MDPI excluded because any open access related to the topic can be found on Scopus database
- It is true that there are no real Industry 4.0 technologies adopted in Jordan, even though that there is some publishing attesting that, but the reason became known after reviewing the project managers experience and interviewing the authors online. One point the project manager of I4.0Jo mentioned that the institutions are saying that they implemented I4.0 but they didn't implement it and this because they want to be eligible for the project funds.
- Universities in Jordan need more than buying new training software to teach the students about these core technologies of Industry 4.0 They need subscriptions to the necessary tools which, in some cases, are more expensive than the cost of the hardware.
- The real reason of challenges to adopt these technologies in Jordan is the lack of standards in the government to regulate these technologies, especially TRC, and to have permission to buy related IoT technologies, most of which are not regulated, as we can

see from the opinion of the mangers and from reading the white papers of IoT published by TRC.

- The Jordanian labor market lacks skilled human power who can meet the requirements of Operator 4.0, due to the frequent migration of qualified workers to the gulf countries and Germany as mentioned in the open-end question of the skills and competencies survey. Which could be confirmed by contacting many Jordanian employees using LinkedIn platform as well.
- Studies have found that the set of skills existent in the labor force to be able to use the technologies of Industry 4.0, but none of them actually support the scenario of a system down, and we need a certain set of skills to operate the old systems as a contingency plan. Therefore, this dissertation has found and suggested that interpersonal skills and analytical skills are the most important to be developed in case of a system down crisis. According to the study questionnaire and the interviews done with the industry 4.0 project managers.
- Also, this thesis could confirm that the use of Industry 4.0 technologies was pushed by the covid 19 crisis by using these technologies as respond plan to this crisis which could solve too many issues in the world and one of them is the crowded school classes that could be turned online. Now those constancy plans became part of our daily life.
- At last, by using the questionnaire to explore the top management of pharma manufacturers in Jordan, we can see that the replies to the statements confirm that there is a huge cost associated with adopting such projects, and the feasibility of this kind of studies; that can reflect how much the challenges overcome the drivers when considering the matter of adopting this industry.

4.3 Recommendations

1- The need for senior management in Jordanian pharmaceutical companies to support the initiatives of Adopting Industry 4.0 emerging technologies, due to their importance in promoting smart manufacturing and improving the level of manufacturing performance in these companies.

2- Working on training and developing workers in Jordanian pharmaceutical companies to deal with Industry 4.0 by offering various courses and seminars.

3- The need to pay attention to the use of smart manufacturing strategies to enhance manufacturing performance using emerging technology provided by Industry 4.0.

4- It is important to create organizational culture and climate, supportive of Industry 4.0, by changing the organizational philosophy and values that enhance the use of Industry 4.0 by these companies.

5- It is important to change legislation and regulatory standards to accommodate the dynamic changes in the markets, which improves the adoption of Industry 4.0.

6- Invite researchers to conduct future studies focusing on the effects of industry 4.0 technologies such as big data analytics and the Internet of Things on performance in these companies. Also, the further studies to use IoT in terms of flashing floods predictions and dams' management is a must to contribute to the solutions of water insecurity in Jordan.

4.4 Limitations and future studies

This thesis encountered a set of limitations as follows:

- This thesis used the questionnaire as a method for collecting data, so it is possible to conduct studies that focus on interviews or reports published in future studies in the pharm industry in Jordan.
- The study model was developed through a group of internal factors in the companies, so it is useful to conduct new studies that consider the organizational level and the individual level within the organization.

- There was no response from both the German side, which left the project of Industry 4.0, and also no real response forms the Polish side of the project, where they have indicated that they are out of office for 4 months.
- The internet coverage maps were not produced by the government.
- The statistical reports which could be downloaded from TRC, statics department of Jordan and the innovation ministry were not accurate comparing it with the investment

bank reports. Also, many of the reports are from the year of 2018, which means that there is lack of the studies about the situation in Jordan.

- All the reports that could be found were affected by the time of the COVID-19 crisis which made the data contain outliers.
- Surveying the pharmaceutical manufacturing study sample of this dissertation was almost imposable because of the conflict of interest it might cause for those companies.
- Now we can see that the AI applications are wieldy used and we can see that some of these application is open access to anyone and this itself is a challenge to humans; here two examples which have been replacing programmers and IT related professions: Chat GPT open AI is a website that has been trained with a huge database that can write a code in less than a minute; another website which is threatening research and development is called Jenni.ai. These AI, as much as others which are paid, are compromising the ethics and code of honor in the scientific researches. It also recommended to have further research to compare the research using AI and Human in this study the comparison took place of what open AI applications could do and it lacks of the real citations and real references and mix both together but after more than three attempts to compare the study results and what AI can generate it was found that Human scientific research is more reliable using scientific research methods and mixing them with ML but still this topic needs more study using controlled samples.

Here this dissertation project can end with the note that (believe nothing of what you hear, half of what you read and all of what you see) but AI and IoT simulation made it hard to believe even what you see on video and pictures. and because this research is a human centric research it must ask what are the skills we need if the system fails? Would the next generation handle human work using old tools and methods? And the last remark that this thesis was written in human way of writing and arguing results and discussions which can be seen if we compare to AI writing methods which are available nowadays. AI can know more than Human in many fields but still it does not have creativity of a human as well as it cannot have a decision

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References

Abbasi, M., Hosnavi, R., & Tabrizi, B. (2013). Application of Fuzzy DEMATEL in Risks Evaluation of Knowledge-Based Networks. *Journal of Optimization*, *2013*(December), 1–7. https://doi.org/10.1155/2013/913467

Abdi Khalife, M., Dunay, A., & Illés, C. B. (2020). Bibliometric Analysis of Articles on Project Management Research. *Periodica Polytechnica Social and Management Sciences*, *29*(1), 70–83. https://doi.org/10.3311/PPso.15717

Abideen, A., & Mohamad, F. B. (2021). Improving the performance of a Malaysian pharmaceutical warehouse supply chain by integrating value stream mapping and discrete event simulation. *Journal of Modelling in Management*, *16*(1), 70–102. https://doi.org/10.1108/JM2-07-2019-0159

Adimuthu, R., Muduli, K., Ray, M., Singh, S., & Ahmad, T. S. T. (2022). Exploring Role of Industry 4.0 Techniques for Building a Promising Circular Economy Concept: Manufacturing Industry Perspective. In *Machine Learning Adoption in Blockchain-Based Intelligent Manufacturing* (pp. 111–124). CRC Press.

Adolph, S., Tisch, M., & Metternich, J. (2014). Challenges and Approaches To Competency Development for Future Production. *Journal of International Scientific Publications*, *12*, 1001–1010.

Adolph, S., Tisch, M., Metternich, J., & Tools, M. (2020). *ISSN 1314-7277, Volume 12, 2014*. *12*, 1001–1010.

Alabbadi, I. (2015a). Implementation of Health Technology Assessment in emerging economies in the MENA region View project Pharmaceutical Business and Pharmaceutical Industry: New Tracks in Pharmacy Education Initiated in Jordan. In *Article in Jordan Journal of Pharmaceutical Sciences* (Vol. 8, Issue 3). https://www.researchgate.net/publication/282571700

Alabbadi, I. (2015b). Pharmaceutical business and pharmaceutical industry: New tracks in pharmacy education initiated in Jordan. *Jordan Journal of Pharmaceutical Sciences*, *8*(3), 217–227.

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. *Engineering Science and Technology, an International Journal*, *22*(3), 899–919. https://doi.org/10.1016/j.jestch.2019.01.006

Alhloul, A., & Kiss, E. (2022). Industry 4.0 as a Challenge for the Skills and Competencies of the Labor Force: A Bibliometric Review and a Survey. *Sci*, *4*(3), 34. https://doi.org/10.3390/sci4030034

Al-Khatib, A. W., & Al-ghanem, E. M. (2022). Radical innovation, incremental innovation, and competitive advantage, the moderating role of technological intensity: evidence from the manufacturing sector in Jordan. *European Business Review*, *34*(3), 344–369.

Alomari, M., & Saqfalhait, N. (2015). Analyzing the structure of Jordanian pharmaceutical industry. *Eur. J. Soc. Sci*, *49*(1).

Alomari, M. W., Alomari, M., & Saqfalhait, N. (2015). Analyzing the Structure of Jordanian Pharmaceutical Industry. In *Article in European Journal of Social Sciences*. https://www.researchgate.net/publication/323907299

Al-Shaikh, M. S., Torres, I. M., Zuniga, M. A., & Ghunaim, A. (2011). Jordanian pharmaceutical companies: Are their marketing efforts paying off? *Health Marketing Quarterly*, *28*(2), 174–189. https://doi.org/10.1080/07359683.2011.572026

Al-Zyadat, A. T., Alsaraireh, J. M., Al-Husban, D. A. O., Al-Shorman, H. M., Mohammad, A. A. S., Alathamneh, F. F., & Al-Hawary, S. I. S. (2022). The effect of industry 4.0 on sustainability of industrial organizations in Jordan. *International Journal of Data and Network Science*, *6*(4), 1437–1446. https://doi.org/10.5267/j.ijdns.2022.5.007

Ananiadou, K., & Claro, M. (2009). *21st century skills and competences for new millennium learners in OECD countries*.

Anderl, R., Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G., & Wahlster, W. (2014). Industrie 4.0-advanced engineering of smart products and smart production. In *Proceedings of international seminar on high technology* (Vol. 19). Herbert Utz Verlag.

Armbrust, M., Stoica, I., Zaharia, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konwinski, A., Lee, G., Patterson, D., & Rabkin, A. (2010). A view of cloud computing. *Communications of the ACM*, *53*(4), 50. https://doi.org/10.1145/1721654.1721672

Armstrong, S., Łupicka, A., Grzybowska, K., Manuti, A., de Palma, P. D., Board, E., Fitsilis, P., Tsoutsa, P., Gerogiannis, V., Prince, K. A., Grzybowska, K., Anna, L., Li, W., Liu, K., Belitski, M., Ghobadian, A., Regan, N. O., Atiku, S. O., Kim, S., … Kohl, H. (2019). Industry 4.0: Required Personnel Competences. *Digital HR: A Critical Management Approach to the Digitilization of Organizations*, *9*(3), 130–133. https://doi.org/10.1007/978-3-319-60210-3

Aspray, W. (1997). The Intel 4004 microprocessor: what constituted invention? *IEEE Annals of the History of Computing*, *19*(3), 4–15. https://doi.org/10.1109/85.601727

Bag, S., Wood, L. C., Xu, L., Dhamija, P., & Kayikci, Y. (2020). Big data analytics as an operational excellence approach to enhance sustainable supply chain performance. *Resources, Conservation and Recycling*, *153*(October 2019), 104559. https://doi.org/10.1016/j.resconrec.2019.104559

Bagheri, B., Yang, S., Kao, H.-A., & Lee, J. (2015). Cyber-physical Systems Architecture for Self-Aware Machines in Industry 4.0 Environment. *IFAC-PapersOnLine*, *48*(3), 1622–1627. https://doi.org/10.1016/j.ifacol.2015.06.318

Bakos, L., Dumitraşcu, D. D., & Harangus, K. (2019). Human factor preparedness for decentralized crisis management and communication in cyber-physical systems. *Sustainability (Switzerland)*, *11*(23). https://doi.org/10.3390/su11236676

Bennett, J. W., & Chung, K.-T. (2001). *Alexander Fleming and the discovery of penicillin*.

Bernard, H. R., & Ryan, G. (1998). Text analysis. *Handbook of Methods in Cultural Anthropology*, *613*.

Birkel, H., Veile, J., Müller, J., Hartmann, E., & Voigt, K.-I. (2019). Development of a Risk Framework for Industry 4.0 in the Context of Sustainability for Established Manufacturers. *Sustainability*, *11*(2), 384. https://doi.org/10.3390/su11020384

Blayone, T. J. B., & VanOostveen, R. (2021). Prepared for work in Industry 4.0? Modelling the target activity system and five dimensions of worker readiness. *International Journal of Computer Integrated Manufacturing*, *34*(1), 1–19. https://doi.org/10.1080/0951192X.2020.1836677

Bogart, D., Bottomley, S., Satchell, M., & Taylor, L. S. (2017). *Transport Networks and the Adoption of Steam Engines in England and Wales, 1761-1800*. Working paper.

Bowler, A. L., Bakalis, S., & Watson, N. J. (2020). Monitoring mixing processes using ultrasonic sensors and machine learning. *Sensors (Switzerland)*, *20*(7). https://doi.org/10.3390/s20071813

Bozkurt, Y., & Karayel, E. (2021). 3D printing technology; methods, biomedical applications, future opportunities and trends. In *Journal of Materials Research and Technology* (Vol. 14, pp. 1430–1450). Elsevier Editora Ltda. https://doi.org/10.1016/j.jmrt.2021.07.050

Brunner, D., Lemoine, G., Greidanus, H., & Bruzzone, L. (2010). Radar imaging simulation for urban structures. *IEEE Geoscience and Remote Sensing Letters*, *8*(1), 68–72.

Caputo, F., Garcia-Perez, A., Cillo, V., & Giacosa, E. (2019). A knowledge-based view of people and technology: directions for a value co-creation-based learning organisation. *Journal of Knowledge Management*, *23*(7), 1314–1334. https://doi.org/10.1108/JKM-10-2018-0645

Casian, T., Nagy, B., Kovács, B., Galata, D. L., Hirsch, E., & Farkas, A. (2022). Challenges and Opportunities of Implementing Data Fusion in Process Analytical Technology—A Review. In *Molecules* (Vol. 27, Issue 15). MDPI. https://doi.org/10.3390/molecules27154846

Castillo, C. (2016). Big crisis data: Social media in disasters and time-critical situations. In *Big Crisis Data: Social Media in Disasters and Time-Critical Situations*. Cambridge University Press. https://doi.org/10.1017/9781316476840

Cerika, A., & Maksumic, S. (2017). *The Effects of New Emerging Technologies on Human Resources: Emergence of Industry 4.0, a Necessary Evil?* Universitetet i Agder; University of Agder.

Chang, J., He, J., Mao, M., Zhou, W., Lei, Q., Li, X., Li, D., Chua, C.-K., & Zhao, X. (2018). Advanced material strategies for next-generation additive manufacturing. *Materials*, *11*(1), 166.

Chen, Y., Yang, O., Sampat, C., Bhalode, P., Ramachandran, R., & Ierapetritou, M. (2020). Digital twins in pharmaceutical and biopharmaceutical manufacturing: A literature review. In *Processes* (Vol. 8, Issue 9). MDPI AG. https://doi.org/10.3390/pr8091088

Chiacchio, F., Compagno, L., D'Urso, D., Velardita, L., & Sandner, P. (2020). A decentralized application for the traceability process in the pharma industry. *Procedia Manufacturing*, *42*, 362–369.

Chiacchio, F., D'urso, D., Oliveri, L. M., Spitaleri, A., Spampinato, C., & Giordano, D. (2022). A Non-Fungible Token Solution for the Track and Trace of Pharmaceutical Supply Chain. *Applied Sciences (Switzerland)*, *12*(8). https://doi.org/10.3390/app12084019

David, H. (2015). Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives*, *29*(3), 3–30.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 319–340.

Ding, B. (2018). Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains. *Process Safety and Environmental Protection*, *119*, 115–130. https://doi.org/10.1016/j.psep.2018.06.031

Dunham, D. (1956). *Building an Egyptian pyramid*. Verlag nicht ermittelbar.

Dworschak, B., Zaiser, H., Fareri, S., Chiarello, F., Coli, E., Teloni, D., Dente, G., Fantoni, G., Mourtzis, D., Dworschak, B., Zaiser, H., Blayone, T. J. B., VanOostveen, R., Razali, H., Abbasi, M., Hosnavi, R., Tabrizi, B., Adolph, S., Tisch, M., … Krstić, Ž. (2014). Competences for cyber-physical systems in manufacturing-First findings and scenarios. *Procedia CIRP*, *25*(C), 345–350. https://doi.org/10.1016/j.procir.2014.10.048

Elbadawi, M., McCoubrey, L. E., Gavins, F. K. H., Ong, J. J., Goyanes, A., Gaisford, S., & Basit, A. W. (2021). Harnessing artificial intelligence for the next generation of 3D printed medicines. In *Advanced Drug Delivery Reviews* (Vol. 175). Elsevier B.V. https://doi.org/10.1016/j.addr.2021.05.015

Elbadawi, M., Ong, J. J., Pollard, T. D., Gaisford, S., & Basit, A. W. (2021). Additive Manufacturable Materials for Electrochemical Biosensor Electrodes. In *Advanced Functional Materials* (Vol. 31, Issue 10). Wiley-VCH Verlag. https://doi.org/10.1002/adfm.202006407

Erol, S., Jäger, A., Hold, P., Ott, K., & Sihn, W. (2016). Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production. *Procedia CIRP*, *54*, 13–18. https://doi.org/10.1016/j.procir.2016.03.162

Fantini, P., Pinzone, M., & Taisch, M. (2020). Placing the operator at the centre of Industry 4.0 design: Modelling and assessing human activities within cyber-physical systems. *Computers and Industrial Engineering*, *139*. https://doi.org/10.1016/j.cie.2018.01.025

Fareri, S., Chiarello, F., Coli, E., Teloni, D., Dente, G., & Fantoni, G. (2018). Workers 4.0: skills, profiles and jobs in different business functions. In *Fondazione Giacomo Brodolini*.

Fareri, S., Fantoni, G., Chiarello, F., Coli, E., & Binda, A. (2020). Estimating Industry 4.0 impact on job profiles and skills using text mining. *Computers in Industry*, *118*, 103222. https://doi.org/10.1016/j.compind.2020.103222

Fleisch, E., & Mattern, F. (2005). *Das internet der dinge: ubiquitous computing und RFID in der praxis: Visionen, technologien, anwendungen, Handlungsanleitungen*. Springer.

Garmaroodi, M. S. S., Farivar, F., Haghighi, M. S., Shoorehdeli, M. A., & Jolfaei, A. (2021). Detection of Anomalies in Industrial IoT Systems by Data Mining: Study of CHRIST Osmotron Water Purification System. *IEEE Internet of Things Journal*, *8*(13), 10280–10287. https://doi.org/10.1109/JIOT.2020.3034311

Geissbauer, R., Vedso, J., & Schrauf, S. (2016). *Industry 4.0: Building the digital enterprise*.

German, A. (2015). *Industry 4.0*. *April*.

Gilchrist, A. (2016). Smart Factories. In *Industry 4.0* (pp. 217–230). Apress. https://doi.org/10.1007/978-1-4842-2047-4_14

Guest, G., MacQueen, K. M., & Namey, E. E. (2012). Introduction to applied thematic analysis. *Applied Thematic Analysis*, *3*(20), 1–21.

Gülçür, M., Brown, E., Gough, T., Romano, J. M., Penchev, P., Dimov, S., & Whiteside, B. (2020). Ultrasonic micromoulding: Process characterisation using extensive in-line monitoring for micro-scaled products. *Journal of Manufacturing Processes*, *58*, 289–301. https://doi.org/10.1016/j.jmapro.2020.08.033

Haagen, M., Zahler, C., Zimmermann, E., & Al-Najami, M. M. R. (2015). Solar Process Steam for Pharmaceutical Industry in Jordan. *Energy Procedia*, *70*, 621–625. https://doi.org/10.1016/j.egypro.2015.02.169

Halacy, D. S. (1970). *Charles Babbage, father of the computer*. Crowell-Collier Press.

Haller, S., Karnouskos, S., & Schroth, C. (2009). *The Internet of Things in an Enterprise Context* (pp. 14–28). https://doi.org/10.1007/978-3-642-00985-3_2

Hammoudi, S., Aliouat, Z., & Harous, S. (2018). Challenges and research directions for Internet of Things. *Telecommunication Systems*, *67*(2), 367–385. https://doi.org/10.1007/s11235-017-0343-y

Hassan, R., & Ismail, A. A. (2018). Challenge and Issues in Human Capital Development Towards Industry Revolution 4.0. *Proceedings of International Conference on The Future of Education 2018*, *July*, 716–727.

Haug, A., Pedersen, S. G., & Arlbjørn, J. S. (2011). IT readiness in small and medium-sized enterprises. *Industrial Management & Data Systems*.

He, H., Maple, C., Watson, T., Tiwari, A., Mehnen, J., Jin, Y., & Gabrys, B. (2016). The security challenges in the IoT enabled cyber-physical systems and opportunities for evolutionary computing & other computational intelligence. *2016 IEEE Congress on Evolutionary Computation (CEC)*, 1015–1021. https://doi.org/10.1109/CEC.2016.7743900

Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2016). Holistic Approach for Human Resource Management in Industry 4.0. *Procedia CIRP*, *54*, 1–6. https://doi.org/10.1016/j.procir.2016.05.102

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 23–34. https://doi.org/10.1016/j.compind.2017.04.002

Hořejší, P. (2015). Augmented reality system for virtual training of parts assembly. *Procedia Engineering*, *100*, 699–706.

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, *146*(October 2018), 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Hoshimov, A., Rustamov, A., & Rozzokov, J. (2018). Industrial Conveyors' Taxonomy and Its Applications. *Acta of Turin Polytechnic University in Tashkent*, *8*(3), 60–62.

Ismail, F., Kadir, A. A., Khan, M. A., & Yih, Y. P. (2019). *The Challenges and Role Played among Workers of Department Human Resources Management towards Industry 4 . 0 in SMEs*. *2019*, 90–107. https://doi.org/10.18502/kss.v3i22.5046

Jelsch, M., Roggo, Y., Kleinebudde, P., & Krumme, M. (2021). Model predictive control in pharmaceutical continuous manufacturing: A review from a user's perspective. *European Journal of Pharmaceutics and Biopharmaceutics*, *159*, 137–142. https://doi.org/10.1016/j.ejpb.2021.01.003

Jerman, A., Pejić Bach, M., & Aleksić, A. (2020). Transformation towards smart factory system: Examining new job profiles and competencies. *Systems Research and Behavioral Science*, *37*(2), 388–402. https://doi.org/10.1002/sres.2657

Jones, R. T. (1974). *Thermodynamics and its applications–an overview*.

Jones, S. E. (2013). *Against technology: From the Luddites to neo-Luddism*. Routledge.

Kaasinen, E., Schmalfuß, F., Özturk, C., Aromaa, S., Boubekeur, M., Heilala, J., Heikkilä, P., Kuula, T., Liinasuo, M., Mach, S., Mehta, R., Petäjä, E., & Walter, T. (2020). Empowering and engaging industrial workers with Operator 4.0 solutions. *Computers and Industrial Engineering*, *139*. https://doi.org/10.1016/j.cie.2019.01.052

Kadir, B. A., & Broberg, O. (2021). Human-centered design of work systems in the transition to industry 4.0. *Applied Ergonomics*, *92*(May 2020), 103334. https://doi.org/10.1016/j.apergo.2020.103334

Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group*. Forschungsunion.

Kagermann, H., Lukas, W.-D., & Wahlster, W. (2011). Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. *VDI Nachrichten*, *13*(1), 2–3.

Kagermann, H., Wahlster, W., & Helbig, J. (2013a). Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Final report of the Industrie 4.0 Working Group. *Final Report of the Industrie 4.0 WG*, *April*, 82. https://doi.org/10.13140/RG.2.2.14480.20485

Kagermann, H., Wahlster, W., & Helbig, J. (2013b). Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Final report of the Industrie 4.0 Working Group. *Final Report of the Industrie 4.0 WG*, *April*, 82. https://doi.org/10.13140/RG.2.2.14480.20485

Kamar, B., & Selim, R. (2020). *Jordan Country Diagnostic*. https://www.ebrd.com/publications/country-diagnostics

Kannus, K., & Ilvonen, I. (2018). *Future Prospects of Cyber Security in Manufacturing: Findings from a Delphi Study*. https://doi.org/10.24251/HICSS.2018.599

Khan, S., Ali, S. A., Hasan, N., & Shakil, K. A. (2019). *Big Data Scientific Workflows in the Cloud : Challenges and Future Prospects : Intelligent Edge , Fog and Mist Computing Big Data Scientific Workflows in the Cloud : Challenges and Future* (Issue January). Springer International Publishing. https://doi.org/10.1007/978-3-030-03359-0

Kim, H., Lin, Y., & Tseng, T.-L. B. (2018). A review on quality control in additive manufacturing. *Rapid Prototyping Journal*.

Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by industry 4.0. *Technology in Society*, *64*(October 2020). https://doi.org/10.1016/j.techsoc.2020.101454

Klein, L. J., Marianno, F. J., Albrecht, C. M., Freitag, M., Lu, S., Hinds, N., Shao, X., Bermudez Rodriguez, S., & Hamann, H. F. (2015). PAIRS: A scalable geo-spatial data analytics platform. *Proceedings - 2015 IEEE International Conference on Big Data, IEEE Big Data 2015*. https://doi.org/10.1109/BigData.2015.7363884

Kwahk, K.-Y., & Lee, J.-N. (2008). The role of readiness for change in ERP implementation: Theoretical bases and empirical validation. *Information & Management*, *45*(7), 474–481.

Lachenmaier, J. F., Lasi, H., & Kemper, H.-G. (2017). Simulation of production processes involving cyber-physical systems. *Procedia CIRP*, *62*, 577–582.

Landherr, M., Schneider, U., & Bauernhansl, T. (2016). The Application Center Industrie 4.0 - Industry-driven Manufacturing, Research and Development. *Procedia CIRP*, *57*, 26–31. https://doi.org/10.1016/j.procir.2016.11.006

Lanza, G., Haefner, B., & Kraemer, A. (2015). Optimization of selective assembly and adaptive manufacturing by means of cyber-physical system based matching. *CIRP Annals*, *64*(1), 399–402. https://doi.org/10.1016/j.cirp.2015.04.123

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, *6*(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4

Le, Q. T. T., Doan, T. H. D., le Hoang Thuy To Nguyen, Q., & Nguyen, D. T. P. (2020). Competency gap in the labor market: Evidence from Vietnam. *Journal of Asian Finance, Economics and Business*, *7*(9), 697–706. https://doi.org/10.13106/JAFEB.2020.VOL7.NO9.697

Lee, J., Bagheri, B., & Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, *3*, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

Leiner, B. M., Cerf, V. G., Clark, D. D., Kahn, R. E., Kleinrock, L., Lynch, D. C., Postel, J., Roberts, L. G., & Wolff, S. (2009). A brief history of the Internet. *ACM SIGCOMM Computer Communication Review*, *39*(5), 22–31.

Liao, Y., Deschamps, F., Loures, E. de F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. *International Journal of Production Research*, *55*(12), 3609–3629.

Longo, F., Nicoletti, L., & Padovano, A. (2017). Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Computers and Industrial Engineering*, *113*, 144–159. https://doi.org/10.1016/j.cie.2017.09.016

Lu, Y., & Xu, X. (2017). A semantic web-based framework for service composition in a cloud manufacturing environment. *Journal of Manufacturing Systems*, *42*, 69–81. https://doi.org/10.1016/j.jmsy.2016.11.004

Lukowski, F., Baum, M., & Mohr, S. (2021). Technology, tasks and training–evidence on the provision of employer-provided training in times of technological change in Germany. *Studies in Continuing Education*, *43*(2), 174–195. https://doi.org/10.1080/0158037X.2020.1759525

Luthra, S., & Mangla, S. K. (2018a). Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Safety and Environmental Protection*, *117*, 168–179. https://doi.org/10.1016/j.psep.2018.04.018

Luthra, S., & Mangla, S. K. (2018b). Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Safety and Environmental Protection*, *117*, 168–179. https://doi.org/10.1016/j.psep.2018.04.018

Madakam, S., Lake, V., Lake, V., & Lake, V. (2015). Internet of Things (IoT): A literature review. *Journal of Computer and Communications*, *3*(05), 164.

Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., & Byers, A. (2011). Big Data: The Next Frontier for Innovation, Competition, and Productivity. In *McKinsey Global Institute*. https://doi.org/10.1080/01443610903114527

Maslow, A. (1974). *A theory of human motivation*. Lulu. com.

Matthew, N. O. S., Wang, Y., Cui, S., & Musa, S. M. (2017). INDUSTRIAL INTERNET OF THINGS. *International Journal of Advances in Scientific Research and Engineering*, *3*, 1–5. https://doi.org/10.7324/IJASRE.2017.32538

Mell, P., & Grance, T. (2011). The NIST Definition of Cloud Computing, Recommendations of the National Institute of Standards and Technology, NIST Special Publication 800-145. In *Computer Security Division, Information Technology Laboratory. NIST Gaithersburg, MD 20899-8930*. https://doi.org/10.1136/emj.2010.096966

Metropolis, N. (2014). *History of computing in the twentieth century*. Elsevier.

Monostori, L. (2014a). Cyber-physical Production Systems: Roots, Expectations and R&D Challenges. *Procedia CIRP*, *17*, 9–13. https://doi.org/10.1016/j.procir.2014.03.115

Monostori, L. (2014b). Cyber-physical Production Systems: Roots, Expectations and R&D Challenges. *Procedia CIRP*, *17*, 9–13. https://doi.org/10.1016/j.procir.2014.03.115

Mourtzis, D. (2018). Development of skills and competences in manufacturing towards education 4.0: A teaching factory approach. *Lecture Notes in Mechanical Engineering*, *0*(9783319895628), 194–210. https://doi.org/10.1007/978-3-319-89563-5_15

Mourtzis, D., Vlachou, E., & Milas, N. (2016). Industrial Big Data as a Result of IoT Adoption in Manufacturing. *Procedia CIRP*, *55*, 290–295. https://doi.org/10.1016/j.procir.2016.07.038

Mrugalska, B., & Wyrwicka, M. K. (2017). Towards Lean Production in Industry 4.0. *Procedia Engineering*, *182*, 466–473. https://doi.org/10.1016/j.proeng.2017.03.135

Mryyan, N. (2014). Demographics, labor force participation, and unemployment in Jordan. *The Jordanian Labour Market in the New Millennium*, 39–63.

Muirhead, J. P. (2022). *The Life of James Watt*. BoD–Books on Demand.

Muñiz Castro, B., Elbadawi, M., Ong, J. J., Pollard, T., Song, Z., Gaisford, S., Pérez, G., Basit, A. W., Cabalar, P., & Goyanes, A. (2021). Machine learning predicts 3D printing performance of over 900 drug delivery systems. *Journal of Controlled Release*, *337*, 530–545. https://doi.org/10.1016/j.jconrel.2021.07.046

Musamih, A., Salah, K., Jayaraman, R., Arshad, J., Debe, M., Al-Hammadi, Y., & Ellahham, S. (2021). A blockchain-based approach for drug traceability in healthcare supply chain. *IEEE Access*, *9*, 9728–9743.

Nickinson, A. T. O., Carey, F., Tan, K., Ali, T., & Al-Jundi, W. (2020). Has the COVID-19 Pandemic Opened Our Eyes to the Potential of Digital Teaching? A Survey of UK Vascular Surgery and Interventional Radiology Trainees. *European Journal of Vascular and Endovascular Surgery*, *xxxx*, 9–10. https://doi.org/10.1016/j.ejvs.2020.09.010

Ong, S. K., Yew, A. W. W., Thanigaivel, N. K., & Nee, A. Y. C. (2020). Augmented reality-assisted robot programming system for industrial applications. *Robotics and Computer-Integrated Manufacturing*, *61*(June 2019), 101820. https://doi.org/10.1016/j.rcim.2019.101820

Papetti, A., Gregori, F., Pandolfi, M., Peruzzini, M., & Germani, M. (2021). A method to improve workers' well-being toward human-centered connected factories. *Journal of Computational Design and Engineering*, *7*(5), 630–643. https://doi.org/10.1093/jcde/qwaa047

Pejic-Bach, M., Bertoncel, T., Meško, M., & Krstić, Ž. (2020). Text mining of industry 4.0 job advertisements. *International Journal of Information Management*, *50*(July), 416–431. https://doi.org/10.1016/j.ijinfomgt.2019.07.014

Piro, T. J. (1998). *The political economy of market reform in Jordan*. Rowman & Littlefield.

Probst, L., Pedersen, B., Lonkeu, O. K., Martinez-Diaz, C., Araujo, L. N., Klitou, D., Conrads, J., & Rasmussen, M. (2017). Digital Transformation Scoreboard 2017: Evidence of positive outcomes and current opportunities for EU businesses. *The European Commission: Brussels, Belgium*.

Qin, J., Liu, Y., & Grosvenor, R. (2016). A Categorical Framework of Manufacturing for Industry 4.0 and beyond. *Procedia CIRP*, *52*, 173–178. https://doi.org/10.1016/j.procir.2016.08.005

Randall, A. (2002). *Before the Luddites: Custom, community and machinery in the English woollen industry, 1776-1809*. Cambridge University Press.

Razali, H. (2018). *Challenge and Issues in Human Capital Development B12*. *July*, 10–12.

Rhee, J., Park, T., & Lee, D. H. (2010). Drivers of innovativeness and performance for innovative SMEs in South Korea: Mediation of learning orientation. *Technovation*, *30*(1), 65–75. https://doi.org/10.1016/j.technovation.2009.04.008

Robinson, E. (1970). James Watt, engineer and man of science. *Notes and Records of the Royal Society of London*, *24*(2), 221–232.

Roldán, J. J., Crespo, E., Martín-Barrio, A., Peña-Tapia, E., & Barrientos, A. (2019). A training system for Industry 4.0 operators in complex assemblies based on virtual reality and process mining. *Robotics and Computer-Integrated Manufacturing*, *59*(May), 305–316. https://doi.org/10.1016/j.rcim.2019.05.004

Romero, D., Bernus, P., Noran, O., Stahre, J., & Fast-Berglund, Å. (2016). The operator 4.0: human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems. *IFIP International Conference on Advances in Production Management Systems*, 677–686.

Romero, D., Wuest, T., Stahre, J., & Gorecky, D. (2017). Social factory architecture: Social networking services and production scenarios through the social internet of things, services and people for the social operator 4.0. *IFIP Advances in Information and Communication Technology*, *513*, 265–273. https://doi.org/10.1007/978-3-319-66923-6_31

Ruppert, T., Jaskó, S., Holczinger, T., & Abonyi, J. (2018). Enabling technologies for operator 4.0: A survey. *Applied Sciences (Switzerland)*, *8*(9), 1–19. https://doi.org/10.3390/app8091650

Salkin, C., Oner, M., Ustundag, A., & Cevikcan, E. (2018). A conceptual framework for Industry 4.0. In *Industry 4.0: managing the digital transformation* (pp. 3–23). Springer.

Samad, T., & Annaswamy, A. M. (2011). The impact of control technology. *IEEE Control Systems Society*, 160–167.

Scheffer, S., Martinetti, A., Damgrave, R., Thiede, S., & van Dongen, L. (2021). How to make augmented reality a tool for railway maintenance operations: Operator 4.0 perspective. *Applied Sciences (Switzerland), 11*(6). https://doi.org/10.3390/app11062656

Segovia, V. R., & Theorin, A. (2012). History of Control History of PLC and DCS. *University of Lund*.

Segura, Á., Diez, H. v., Barandiaran, I., Arbelaiz, A., Álvarez, H., Simões, B., Posada, J., García-Alonso, A., & Ugarte, R. (2020). Visual computing technologies to support the Operator 4.0. *Computers and Industrial Engineering, 139*. https://doi.org/10.1016/j.cie.2018.11.060

Sezer, O. B., Dogdu, E., & Ozbayoglu, A. M. (2017). Context-aware computing, learning, and big data in internet of things: a survey. *IEEE Internet of Things Journal*, *5*(1), 1–27.

Shamim, S., Cang, S., Yu, H., & Li, Y. (2016). *Management Approaches for Industry 4.0*. 5309–5316.

Shariatzadeh, N., Lundholm, T., Lindberg, L., & Sivard, G. (2016). Integration of Digital Factory with Smart Factory Based on Internet of Things. *Procedia CIRP*, *50*, 512–517. https://doi.org/10.1016/j.procir.2016.05.050

Shqair, M. I., & Altarazi, S. A. (2022). Evaluating the Status of SMEs in Jordan with Respect to Industry 4.0: A Pilot Study. *Logistics*, *6*(4), 69. https://doi.org/10.3390/logistics6040069

Stachová, K., Stacho, Z., Cagánová, D., & Starecek, A. (2020). Use of digital technologies for intensifying knowledge sharing. *Applied Sciences (Switzerland)*, *10*(12). https://doi.org/10.3390/app10124281

Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., & Haug, A. (2021). Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. *Production Planning & Control*, *32*(10), 811–828. https://doi.org/10.1080/09537287.2020.1768318

Stentoft, J., Rajkumar, C., & Madsen, E. S. (2017). Industry 4.0 in Danish Industry. *Department of Entrepreneurship and Relationship Management, University of Southern Denmark*.

Stuart, B. L. (2018). Programming the ENIAC [Scanning our Past]. *Proceedings of the IEEE, 106*(9), 1760–1770. https://doi.org/10.1109/JPROC.2018.2843998

Subekti, S., Ana, A., Barliana, M. S., & Khoerunnisa, I. (2019). Problem solving improvement through the teaching factory model. *Journal of Physics: Conference Series*, *1402*(2). https://doi.org/10.1088/1742-6596/1402/2/022044

Suri, K., Cuccuru, A., Cadavid, J., Gerard, S., Gaaloul, W., & Tata, S. (2017). Model-based Development of Modular Complex Systems for Accomplishing System Integration for Industry 4.0. *MODELSWARD*, 487–495.

Syberfeldt, A., Danielsson, O., & Gustavsson, P. (2017). Augmented reality smart glasses in the smart factory: Product evaluation guidelines and review of available products. *Ieee Access*, *5*, 9118–9130.

Szabó-Szentgróti, G., Végvári, B., & Varga, J. (2021). Impact of Industry 4.0 and Digitization on Labor Market for 2030-Verification of Keynes' Prediction. *Sustainability*, *13*(14), 7703. https://doi.org/10.3390/su13147703

Thurston, R. H. (1884). On the development of the theory of the steam engine and its application. An historical outline sketch. *Journal of the Franklin Institute*, *118*(4), 241–262.

Tomasello, M. (2018). *A natural history of human thinking*. Harvard University Press.

Trust, D. (2019). *The Cybersecurity Guide for Leaders in Today ' s Digital World*. *October*.

van Eck, N. J., & Waltman, L. (2011). VOSviewer manual. *Manual for VOSviewer Version*, *1*(0).

Wadan, R., Bensberg, F., Teuteberg, F., & Buscher, G. (2019). Understanding the changing role of the management accountant in the age of industry 4.0 in Germany. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2019-Janua*(January), 5817–5826. https://doi.org/10.24251/hicss.2019.702

Wagner, D., & Schmalstieg, D. (2009). History and future of tracking for mobile phone augmented reality. *Proceedings - 2009 International Symposium on Ubiquitous Virtual Reality, ISUVR 2009*. https://doi.org/10.1109/ISUVR.2009.11

Walendowski, J., Kroll, H., & Schnabl, E. (2016a). Industry 4.0, advanced materials (nanotechnology). *Regional Innovation Monitor Plus*.

Walendowski, J., Kroll, H., & Schnabl, E. (2016b). Regional Innovation Monitor Plus 2016: Thematic Paper 3-Industry 4.0. *Advanced Materials (Nanotechnology)*.

Wang, C., Cheng, Z., Yue, X.-G., & McAleer, M. (2020). Risk Management of COVID-19 by Universities in China. *Journal of Risk and Financial Management*, *13*(2), 36. https://doi.org/10.3390/jrfm13020036

Whysall, Z., Owtram, M., & Brittain, S. (2019). The new talent management challenges of Industry 4.0. *Journal of Management Development*, *38*(2), 118–129. https://doi.org/10.1108/JMD-06-2018-0181

Witkowski, K. (2017). Internet of Things, Big Data, Industry 4.0 – Innovative Solutions in Logistics and Supply Chains Management. *Procedia Engineering*, *182*, 763–769. https://doi.org/10.1016/j.proeng.2017.03.197

Wübbeke, J., Meissner, M., Zenglein, M. J., Ives, J., & Conrad, B. (2016). Made in china 2025. *Mercator Institute for China Studies. Papers on China*, *2*, 74.

Xu, X. (2012). From cloud computing to cloud manufacturing. *Robotics and Computer-Integrated Manufacturing*, *28*(1), 75–86. https://doi.org/10.1016/j.rcim.2011.07.002

Yadav, A. K., & Kumar, D. (2023). Blockchain technology and vaccine supply chain: Exploration and analysis of the adoption barriers in the Indian context. *International Journal of Production Economics*, *255*, 108716.

Yu, C., Xu, X., & Lu, Y. (2015). Computer-integrated manufacturing, cyber-physical systems and cloud manufacturing–concepts and relationships. *Manufacturing Letters*, *6*, 5–9.

Zakhama, A., Charrabi, L., & Jelassi, K. (2019). Intelligent Selective Compliance Articulated Robot Arm robot with object recognition in a multi-agent manufacturing system. *International Journal of Advanced Robotic Systems*, *16*(2), 1729881419841145.

Zhang, Q., Cheng, L., & Boutaba, R. (2010). Cloud computing: state-of-the-art and research challenges. *Journal of Internet Services and Applications*, *1*(1), 7–18. https://doi.org/10.1007/s13174-010-0007-6

Zhou, K., Liu, T., & Zhou, L. (2015). Industry 4.0: Towards future industrial opportunities and challenges. *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, 2147–2152.

Zobel-Roos, S., Schmidt, A., Uhlenbrock, L., Ditz, R., Köster, D., & Strube, J. (2021). Digital Twins in Biomanufacturing. *Advances in Biochemical Engineering/Biotechnology*, *176*, 181–262. https://doi.org/10.1007/10_2020_146

Appendix

Appendix 1 : Top cited articles about Pharma 4.0 WOS database

Number Of citations	links	Document title	Journal name	Journals impact factor	journals cite score
63	5	Current Perspectives on the Development of Industry 4.0 in the Pharmaceutical Sector	Journal of Industrial Information Integration	11.718	20.9
55	1	Reconfigurable Smart Factory for Drug Packing in Healthcare Industry 4.0	IEEE Transactions on Industrial Informatics	11.648	21.3
50	3	Translating 3D printed pharmaceuticals: From hype to real-world clinical applications	Advanced Drug Delivery Reviews	17.873	22.3

40	8	Digital Twins in Pharmaceutical and Biopharmaceutical Manufacturing: A Literature Review	Processes	3.352	3.5
33	2	Additive Manufacturable Materials for Electrochemical Biosensor Electrodes	Advanced functional material	19.924	N/A
28	3	Machine learning predicts 3D printing performance of over 900 drug delivery systems	Journal of Controlled Release	11.467	15.7
26	7	Industry 4.0 for pharmaceutical manufacturing: Preparing for the smart factories of the future	International Journal of Pharmaceutics	6.51	9.6
24	2	Modelling the enablers of industry 4.0 in the Indian manufacturing industry	International Journal of Productivity and Performance Management	3.99	0.578
24	6	Harnessing artificial intelligence for the next generation of 3D printed medicines	Advanced Drug Delivery Reviews	17.873	22.3
20	0	3D printing technology; methods, biomedical applications, future opportunities, and trends	Journal of Materials Research and Technology	6.267	5.9
20	5	Connected healthcare: Improving patient care using digital health technologies	Advanced Drug Delivery Reviews	17.873	22.3
19	4	Cyber-physical-based PAT (CPbPAT) framework for Pharma 4.0	International Journal of Pharmaceutics	6.51	9.6
16	0	Improving the performance of a Malaysian pharmaceutical warehouse supply chain by integrating value stream mapping and discrete event simulation	Journal of Modelling in Management	2.77	0.465
16	0	On the verge of the market – Plant factories for the automated and standardized production of biopharmaceuticals	Biotechnology Advances	17.681	26.9
14	0	Monitoring Mixing Processes Using Ultrasonic Sensors and Machine Learning	Sensors	3.847	N/A

12	2	Smart Pharmaceutical Manufacturing: Ensuring End-to-End Traceability and Data Integrity in Medicine Production	Big Data Research	3.739	5.4
11	0	Detection of Anomalies in Industrial IoT Systems by Data Mining: Study of CHRIST Osmotron Water Purification System	IEEE Internet of Things Journal	10.238	17.1
10	2	Emerging Challenges and Opportunities in Pharmaceutical Manufacturing and Distribution	sensors	3.847	N/A
10	0	Ultrasonic micromoulding: Process characterization using extensive in-line monitoring for micro-scaled products	Journal of Manufacturing Processes	5.684	7.6
8	0	Digital Twins in Biomanufacturing	full article is not included	N/A	
7	2	Model predictive control in pharmaceutical continuous manufacturing: A review from a user's perspective	European Journal of Pharmaceutics and Biopharmaceutics	5.589	9.7
5	2	Moving Towards Industry 5.0 in the Pharmaceutical Manufacturing Sector: Challenges and Solutions for Germany	IEEE Transactions on Engineering Management	8.702	6.2
5	0	A Non-Fungible Token Solution for the Track and Trace of Pharmaceutical Supply Chain	Applied Sciences	2.838	3.7
1	2	Challenges and Opportunities of Implementing Data Fusion in Process Analytical Technology—A Review	Molecules	4.927	N/A
0	3	Application of Artificial Neural Networks in the Process Analytical Technology of Pharmaceutical Manufacturing—a Review	An Official Journal of the American Association of Pharmaceutical Scientists	3.603	N/A

Appendix 2 : Top cited articles about Pharma 4.0 Scopus database

Citations	links	Document title	Journal name	Journal impact factor	Journals cite score
152	0	Cloud manufacturing as a sustainable process manufacturing route	Journal of Manufacturing Systems	9.498	15
140	9	Reshaping drug development using 3D printing	Drug Discovery Today	8.369	14.7
127	4	Artificial intelligence in drug discovery and development	Drug Discovery Today	8.369	14.7
113	47	Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains	Process Safety and Environmental Protection	7.9626	9.9
102	0	Big Data Analytics in Chemical Engineering	Annual Review of Chemical and Biomolecular Engineering	9.7	N/A
95	3	Smart Packaging: Opportunities and Challenges	Procedia CIRP		3.9
86	0	Green technology innovation development in China in 1990–2015	Science of The Total Environment	10.753	14.1
82	3	Bioprocessing in the Digital Age: The Role of Process Models	Biotechnology Journal	3.543	
75	3	The Digital Pharmacies Era: How 3D Printing Technology Using Fused Deposition Modeling Can Become a Reality	Pharmaceutics	6.525	
74	0	Reconfigurable Smart Factory for Drug Packing in Healthcare Industry 4.0	IEEE Transactions on Industrial Informatics	11.648	21.3
73	9	Current Perspectives on the Development of Industry 4.0 in the Pharmaceutical Sector	Journal of Industrial Information Integration	11.718	20.9

62	0	Biomanufacturing: history and perspective	journal of industrial microbiology and biotechnology	4.258	
60	0	Internet of Things research in supply chain management and logistics: A bibliometric analysis	Internet of Things	5.711	10.2
55	2	Translating 3D printed pharmaceuticals: From hype to real-world clinical applications	Advanced Drug Delivery Reviews	17.873	22.3
53	2	A Blockchain and Machine Learning-Based Drug Supply Chain Management and Recommendation System for Smart Pharmaceutical Industry	electronics	2.69	3.7
51	0	Additive Manufacturing Technologies for Drug Delivery Applications	International Journal of Pharmaceutics	6.51	9.6
51	2	3D printing by fused deposition modeling of single- and multi-compartment hollow systems for oral delivery – A review	International Journal of Pharmaceutics	6.51	9.6
50	13	Digital Twins in Pharmaceutical and Biopharmaceutical Manufacturing: A Literature Review	processes	3.352	3.5
48	12	Data science tools and applications on the way to Pharma 4.0	Drug Discovery Today	8.369	14.7
46	0	Additive manufacturing in drug delivery applications: A review	International Journal of Pharmaceutics	6.51	9.6

Appendix 3: Industry 4.0 skills and competencies Survey

I would like to ask you to fill the following form on the new skills and competencies required by Industry 4.0. This survey is important for my PhD studies as I am the student of the Széchenyi István Doctoral School of Sopron University, so I kindly ask you to help my research by filling the form. Please write down all your experiences gained at your workplace on this issue, how robotization, automation and digitalization affect your work, what kind of new skills and competencies are needed. In a matter of fact there is a risk of human being replaced by the machines in most of the industries because of this new industrial revolution and this research a human centric that is trying to fill the gap that is existed in the labor market by highlighting the needed skills and to which technology of industry, it is related. I use confidently the information and data only for my PhD research.

Thank you for your support

The Author

Section (1)

- Age
- Gender
- Educational level
- Department / college
- Research area / specialization
- For how long you have been in this specialization?

Section (2): Awareness of industry 4.0 concept and basics

- Have you ever heard of Industry 4.0 or Smart factory or fully automated systems?

Yes/ No

- How did you know about Industry 4.0 or related concepts?

Scientific research / Published books

Surfing/Online advertisements Ex: YouTube

Seminar/workshop in the university

Course book/from the teacher

- Have you ever heard about the following technologies?

Sensor

Additive Manufacturing (3D printing)

Simulation

Augmented Reality (VR)

Autonomous Robots (Artificial intelligence, Machine Learning)

System Integration

Big Data

Cybersecurity

Cloud Manufacturing

Internet of Things (IoT)

Cyber-Physical System (CPS)

Smart Factory

Decentralization / Block chain

Information and communications technology (ICT)

Section (3) In this section please chose your answer between 1 to 5 where (5 = strongly agree) and (1 = strongly disagree)

- The use of sensors have increased in the last 5 years in our life.
- Covid-19 pandemic have increased the level of dependency on IT related systems among the people
- It is the government responsibility to help in realizing the new industrial revolution
- It is the people own responsibility to realize new industrial revolution.
- Industry 4.0 and similar technologies are still at their early stages which can't replace Human at the labor market.
- Robots are replacing the Human in the routine jobs (Ex: self-check in at the airport, self-check out at the supermarket)
- Robots can replace and/or decrease Human workforce in the complicated jobs (Ex; construction related jobs)
- I believe Industry 4.0 needs a different set of skills in order to cope with it.
- Who's responsibility to educate and upskill the Human power about the related and essential skills and competences of Industry 4.0?

Section (4) Please read for better understanding.

In this section already important skills and competences categories have been chosen based on the previous studies. This section has two sub sections, one for measuring how much you have of the skills and the second is about your estimations regarding what is more important

- Please indicate the level of skill you have.

Personal competencies (flexibility, Ambiguity tolerance, motivation to learn, ability to work under pressure, sustainable mindset)

Social/Interpersonal (Intercultural skills, language skills, communication skills, networking skills, team work, ability to transfer knowledge, leadership skills)

Technical (Technical skills, media skills, coding skills)

Methodological (Creativity, research skills, problem solving, conflict solving, decision making)

- Please indicate which skill you find more important in regards of Industry 4.0

- Can you perform tasks using any programing languages?

Yes / No

- If you can use programing languages, please indicate what are those and which one you find the most important in regards of Industry 4.0?

- Please tell us more about what do you think about replacing human by robots and industry 4.0 and similar technologies?

- What kind of new skills or qualifications have gained during last five years?

- Why?

- How do you imagine your work 10 years later?

Appendices 4. Industry 4.0 adoption challenges in the Jordanian pharmaceutical manufacturing

I would like to ask you to fill the following form on the new Industry 4.0 emerging technologies and how it can be adopted in the pharma manufacturing and what are the challenges. This survey is important for my PhD studies as I am the student of the Széchenyi István Doctoral School of Sopron University, so I kindly ask you to help my research by filling the form. Please write down all your experiences gained at your workplace on this issues, how robotization, automation and digitalization can be adopted and what are the main challenges on adopting these technologies in Jordan. I will use confidently the information and data only for my PhD research only and in case of scientific publishing no names or any reasoned of conflict of interest will be caused.

Thank you for your support

Industry 4.0 adoption challenges in the pharmaceutical manufacturing in Jordan

Organization name:

Demographics:

Age:

Gender:

Education:

Department:

Research area:

Years of experience

Likert scale questions please chose the answer which reflect your views the more.

Strongly disagree, disagree, neither agree nor disagree, agree, strongly disagree.

<u>Section 1 Upfront investment/cost</u>

- I believe that the Lack of financial means is a challenge to implement Industry 4.0 in the pharma

manufacturing in Jordan

- Requirement of continuous training and education to upskill the work force to meet the

requirement of industry 4.0 is costly

- Industry 4.0 emerging technologies requires huge Energy costs to operate in pharma

manufacturing

- I believe that there is a lack of infrastructure means in terms of internet and energy in Jordan to

adopt industry 4.0 technologies

- Smart manufacturing technologies have enough finance plans provided by the leading

companies in the related fields

- I believe using renewable energy to operate smart factory technologies is feasible in term of

energy costs

<u>Section 2 Legislation and standards</u>

- There is Lack of standards to regulate the communication methods of Industry 4.0 ex (IoT)

- (import /export) standards are not updated to comply with Industry 4.0 technologies in Jordan

which makes it a challenge to adopt such technologies.

- I believe that laws and regulations in terms of cyber security are not enough to regulate the

adoption of Industry 4.0 in the pharma manufacturing in Jordan.

- I believe that there is a lack of investment promotions standards in the government to attract FDI

(Forging direct investment) to adopt industry 4.0 technologies.

- Renewable energy solutions have lack of standards to be adopted in mass production in the pharmaceutical manufacturing in Jordan

Section 3 Management

- I think that there is a Lack of understanding of the strategic importance of Industry 4.0 in the management of pharma manufacturing in Jordan.

- I believe that the management of pharma manufacturing in Jordan are more focused on operation at the expense of developing the company (ambidexterity)

- Awareness and Change Resistance at the top management level is challenging the adoption of

industry 4.0 in pharma manufacturing.

- I believe the top-level management are more driven to short term profit compared to long term

of adopting new technological means of smart factory

- Top management in the pharmaceutical sector in Jordan are collaborating to create energy plans

- There are enough regulations to drive the consumer behavior based on their needs rather than the production strategies

Section 4 risk

- I believe the Lack of data protection (cyber security) is a challenge to adopt industry 4.0 emerging technologies.

- Using Industry 4.0 emerging technologies will risk of Compatibility with the pharma Regulatory Affairs of FDA, EMA, and MENA standards.

- Using Industry 4.0 emerging technologies in the pharma manufacturing can affect Pharmaceutical continuous manufacturing system in case of system failure risk

- Adopting Industry 4.0 emerging technologies will increase the unemployment rate increasing risk

- I believe using simulation to create risk reduction scenario can help in mitigating unforeseen events in the pharma manufacturing in Jordan

- I believe that using Artificial intelligence in the quality control of medications can increase the health risk compared with humans.

Section 5 work force (Operator 4.0)

- I believe that there is a Lack of qualified work force to operate Industry 4.0 in the pharma industry in Jordan

- There is Lack of employee readiness in terms of awareness and training.

- There is a Lack of understanding the relationship (human-machine) among the work force of pharma manufacturing in Jordan.

- I believe there is a change Resistance in the work force among the pharma manufacturing in Jordan.

- having coding skills will be essential in operating Industry 4.0 technologies in the manufacturing

- I believe that the analytical skills are important to operate Industry 4.0 technologies and basic systems as well

Section 6

Adopting industry 4.0 emerging technologies in the pharmaceutical manufacturing in Jordan

- I believe that using Industry 4.0 emerging technologies in the pharmaceutical manufacturing in

Jordan will increase the quality of the products and reduce the time.

- I believe using digital twin and similar technologies will help the decision makers to have tackle

complexity of the market.

- Industry 4.0 adoption in the pharma manufacturing will increase the volatility, uncertainty, complexity, and ambiguity.

- Adoption of Industry 4.0 technologies such as block chain NFT in pharmaceutical manufacturing

in Jordan will increase the customer satisfaction.

- Industry 4.0 emerging technologies adoption in the pharmaceutical manufacturing sector can play a huge role in the contingency plans in case of crises.

- I believe that adopting industry 4.0 in in the pharmaceutical manufacturing sector will increase the competitive advantage of Jordan in the global pharma market.