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Bibliometric Analysis of the Articles on Industry 4.0 Published in Academic Journals

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ABSTRACT

Purpose – The objective of this study is to conduct a bibliometric analysis of the articles on industry 4.0 between published between 2014 and 2019.

Design/methodology/approach – Within this scope, 120 articles published in 2014-2019 were examined, and they were bibliometrically analyzed in the context of some parameters. The bibliometric analysis was preferred in this quantitative research, and Excel and SPSS programs were used to analyze the obtained data.

Findings – The examination of database, journal, and year parameters showed that the most publications were indexed in the Sciencedirect database, most of which were published in a journal named Procedia Manufacturing in 2019. In addition, it was determined that most of the articles had been previously presented in a scientific meeting, were published by the authors mostly in the journals with themes of manufacturing plants and cyber-physical system.

Discussion – It was determined that some of the bibliometric data obtained at the end of this research are partially similar to the studies in the literature, whereas some results are different from the literature data. Accordingly, it is considered that the present study make a contribution to the literature by creating industry 4.0 awareness from the macro perspective and would encourage enterprises to produce better quality goods and provide better service, and help increase the productivity of various sectors such as health, education and informatics.

1. Introduction

The Fourth Industrial Revolution, one of the most popular topics in professional and academic fields, is also named industry 4.0. The effect of rapid developments in digitalization on industry business processes is expressed as the fourth industrial revolution or industry 4.0. In this process, modern technologies such as augmented reality, blockchain technology, internet of things, and big data have emerged. The concept of industry 4.0 is based on digitalization, and like globalization, digitalization leads to lasting variations in human life, the processes of institutions and organizations, and the structures of societies. Industry 4.0 aims the use of intensive information technology, also called the era of artificial intelligence, to implement industrial change in businesses. The vision of industry 4.0 is to guide manufacturing businesses to acquire high levels of digital capabilities (Frank et., 2019: 15; Hidayatno et al., 2019: 228; Yilmaz and Duman, 2019: 187; Lu et al., 2019: 69; Mantravadi and Møller, 2019: 588). In a way, industry 4.0 can be called the impact of digital developments in technology on the provision of goods and services within the company.

Industry 4.0 is rely on advanced production and is also called the Smart Manufacturing Concept with automated manufacturing processes and flexible production lines. This process aims to sustainably protect resources at a large scale by increasing quality, productivity, and flexibility. At the same time, it enables the management of factories producing complex and flexible products (Frank et al., 2019: 16; Trappey et al., 2017: 593). Briefly stated this concept, which is based on the understanding of smart manufacturing, is a series of processes predicated on the industry's effectiveness, efficiency, and high-quality production in business processes.

[1] This article is an enlarged of the work prepared by the author as an verbal presentation at 6th International Conference on Applied Economics and Finance & Extented Social Sciences (ICOAEF-VI) organized by Bandırma Onyedi Eylul University in Burhaniye between 16-17 November 2019.

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In this study, the bibliometric analysis of articles on industry 4.0 was carried out. For this purpose, the relevant articles published between 2014 and 2019 were scanned in three databases, and various criteria were determined, and the obtained data were analyzed with the SPSS software. The present study was initiated with the aim of creating awareness and curiosity about industry 4.0. Accordingly, the researcher assumed an unbiased orientation, emphatic stance, and ethical principles and stances in the research.

The findings were tabulated, and the results were interpreted and explained taking into account that industry 4.0, emerging from digitalization, causes permanent changes in the activities of enterprises as in all fields. It is considered that this study can contribute to both the literature and practitioners in order for the industry to produce efficiently and effectively and to provide better quality goods and services to customers through high technological possibilities and measures.

2. The Literature Search

The tools of industry 4.0, such as cloud technology, cyber-physical systems and smart factories in small and medium-sized enterprises, have led to complexity and controversy. Looking at the development process of industry 4.0, it is seen that industry 1.0 adopted mechanization and steam power, industry 2.0 adopted mass production and assembly line, industry 3.0 adopted the process of digitalization and automation that began in the 1970s, and that industry 4.0 was designed for the decentralized on-demand production and adopts the principle of resource efficiency. Industry 4.0 is one of today's industrial automation trends that makes it possible to improve new production technologies, efficiency in production, product quality, and business conditions (Jäger et al., 2016: 116; Xu and Duan, 2019: 148; Muscio and Ciffolilli, 2020: 169). This concept is the latest stage of the impact of technological developments from the past to the present on the industry.

The concept of industry 4.0 emerged in 2011 at the Hannover Fair when it was introduced as a strategic approach to production. This program aims to achieve high efficiency, higher revenue, high quality, better customer service, and high safety. Industry 4.0, originated from a project supported by the German government for the vision of advanced production, has become a widely used concept since that time. This vision aims to develop strategies for smart factories with the necessary management adjustments, research on new business models and platforms for new service processes (Ceruti et al., 2019: 516; Mogos et al., 2019: 624; Xu and Duan, 2019: 148; Wagner et al., 2018: 1004). The concept of industry 4.0 first appeared in Germany, bringing high quality and efficiency in production.

Industry 4.0, known as the Fourth Industrial Revolution, realizes the productivity growth in the supply chain by providing faster innovation in production. This paradigm change has affected the production sector and caused the widespread adoption of new digital technologies in the processes of businesses. The physical and digital world have been combined to create the foundation of this Industrial Revolution, which is the basis of smart factories. Many business enterprises aim to build 'smart factory' level facilities in these areas because of their potential, as they want to take advantage of the increased productivity and flexibility and reduced costs (Javaid and Haleem, 2019: 102; Diez-Olivan et al., 2019: 92; Barenji et al., 2019: 1). Digital technology such as smart factories and smart manufacturing aims to increase production efficiency processes by integrating machines.

Various definitions related to industry 4.0 are presented below:

- The process that started with creating the industrial worth in developed countries and ended in the fourth stage of industrialization is expressed as industry 4.0 (Stock and Seliger, 2016: 536).
- The rapid digital technology transformation is called industry 4.0 (Hidayatno et al., 2019: 227).
- Industry 4.0, also referred to as the industrial internet, smart manufacturing, or integrated industry, is a series of industrial revolutions involving manufacturing and industrial processes that transform and affect all industries (Hofmann and Rüsch, 2017: 23).
- The gradual combination of traditional production enabling control over the entire value chain with the latest technological, industrial applications of products and services within their lifecycle is defined as industry 4.0 (Ghobakhloo and Fathi, 2019: 3).

In summary, this concept is defined as the digital transformation of manufacturing processes.

Industry 4.0 involves intelligent manufacturing technologies, intelligent connectivity technologies, big data, and data processing. The industry 4.0 revolution arise from many destructive technologies that enable digitalization in the manufacturing sector. It gives production establishments high digital capacity (Stentoft and Rajkumar, 2020: 2954; Mourtzis et., 2019: 6910; Mantravadi and Møller, 2019: 588).

Cyber-Physical Systems are integrated into traditional engineering approaches to help technologies using industry 4.0 enable the new product development. Besides, the vision of industry 4.0 introduces not only new methods and technologies to enterprises but also new approaches. In other words, it offers new opportunities to increase resource and process efficiency by ensuring autonomy and network formation (Promyoo et., 2019: 1043-1044; Benešová and Tupa, 2017: 2195; Prinz et al., 2017: 159).

The basic objectives of industry 4.0 are to increase production efficiency and decrease costs. It is important to measure and improve the quality in the production process to achieve this objective (Lazarova-Molnar and Mohamed, 2019: 693). This concept aims to increase productivity by giving enterprises a vision and mission in research and development and reducing costs.

Industry 4.0 acknowledges that machines are an interconnected, collaborative community and that predictive manufacturing is possible at the factory. This concept is considered a process that enables enterprises to achieve higher industrial performance. Industry 4.0 helps small and medium-sized businesses dynamically keep track of market opportunities, especially those with limited resources. Industry 4.0 aims to increase the degree of automation and efficiency, and productivity levels in the industry's business processes, and provides greater flexibility and improves smart productivity in production so that businesses can deliver higher quality personalized goods and services to their customers in a shorter time (Lee et al., 2014: 6; Dalenogare et al., 2018: 383; Xu and Duan, 2018: 149; Lu, 2017: 1; Zhong et al., 2017: 616). The concept of industry 4.0 can be used to achieve successful organizational performance management and develop flexible working models for enterprises.

2.1 Previous Studies with Bibliometric Analysis on Industry 4.0

There are some bibliometric analysis studies on industry 4.0 in the literature. They are summarized as follows:

The study conducted by Zabidin et al. (2020) on industry 4.0 in the construction industry using bibliometric, content, and scientific analyses indicated that the USA, England, and China internalized the concept of industry 4.0 in the construction field within a system and often used it in the sector. Accordingly, the publications on the subject revealed that Germany ranks first among the countries, and the publications are concentrated in 2018. Furthermore, it was determined that the articles were mostly published in the journal named Procedia Manufacturing and followed by Procedia CIRP. Among the keywords, it was understood that the word industry 4.0 was used the most. However, it is thought that this study forms a basis for those who will research for industry 4.0 in the future and fills the gap in the literature in terms of practicing industry 4.0 in the construction sector.

The study by Newman et al. (2020) aimed to determine the impediments in the United Kingdom for the construction sector to become widespread and the opportunities that are presented by the concept with the start of industry 4.0 related publications in the literature opportunities that the concept presented by starting the studies on industry 4.0 in the literature. In other words, there were some opportunities for industry 4.0 to develop in the construction sector and to adopt innovations. The research consists of two stages which are literature survey and empirical research. It was determined that the studies about industry 4.0 in the literature were generally conducted in the developed countries led by Germany. Besides, it was confirmed that most studies were published in 2018. The previous research had limitations mentioning that industry 4.0 is merely a technological application, but it is thought that this study has helped industry 4.0 develop its potential in England.

In the study performed by Muhuri et al. (2019) on Scopus and WoS databases, the bibliometric analysis of the most cited articles was done based on total citation count. It was determined that the most used keywords in the articles included in the journals were cyber-physical systems, internet of objects, smart

production, and simulation, respectively. In the WoS and Scopus databases, it was determined that the most publications on the concept of industry 4.0 belonged to Germany. However, this study did not demonstrate the quality of publications, though it gave the numbers of articles and citations referring to the concept of industry 4.0. This is the most important limitation of the study. Another limitation is that Google Scholar database and the access journals were not used in the study. Their study contributes to the literature since it summarizes the studies conducted in the last five years on the structure of industry 4.0.

López-Robles et al. (2020) examined the articles in the Scopus database to measure the performance of the authors and the publications on industry 4.0 and project management by bibliometric analysis. Accordingly, it was confirmed that the authors published the articles mostly in 2019 in the Scopus database and that the publications in these journals were cited. However, it was determined that there has been a remarkable increase in the number of articles published on the subject in the last five years. It is seen that these authors still continue to be interested in the subject. Furthermore, it is thought that this study contributes to the literature due to evaluating the publication performance of the authors on industry 4.0 and project management. Nevertheless, the researchers are recommended that more comprehensive studies be performed on industry 4.0 and project management in the future.

Tepe and Ozcan (2021) conducted a study in the field of social sciences in the Scopus database on industry 4.0 in the last two years through bibliometric analysis. They found 1,084 studies in the Scopus database, but amongst them 540 studies fell into in the field of social sciences. It was understood that the industry 4.0 keyword was used the most in these studies, and German authors got more interested in the publications on the subject. Besides, it was confirmed that the authors published most articles in 2018, and their publications were cited. Furthermore, it was understood that the publications concentrated on business administration and management sciences. On the other hand, the most important limitation of the study is that it was conducted on the subject during the determined years and that it did not measure their quality, despite its focus on the number of publications. However, the difference of this study from the other studies on the subject is that it was carried out in the field of social sciences.

In the study performed by Bigliardi et al. (2021), the articles on industry 4.0 in the logistic field of the Scopus database were reviewed. Accordingly, it was determined that the most articles were published in 2019, and Germany was the country that had the most publications. However, choosing only the bibliometric analysis method and a single database is the most important limitation of this study. The researchers who want to conduct research in the future are recommended to scan the academic databases like Web of Science and Google Scholar, although Scopus is a database showing extensive publications on industry 4.0 in the logistic field. It is thought that this study can be useful for the researchers who will conduct research in the future, as it is the first research on industry 4.0 using the bibliometric analysis method in the logistic area.

Cobo et al. (2018) analyzed the studies on industry 4.0 indexed in the Web of Science database and published between the years of 2013 and 2017 through the bibliometric analysis method. Accordingly, a total of 333 studies were found in the bibliometric analysis through scientific mapping. Besides, it was determined that the studies were most concentrated in 2017, their main theme was mostly cyber-physical systems, and at the same time, this theme was cited the most. However, those who will investigate this subject in the future are recommended to conduct research by adding more time intervals and themes.

3. Method

A quantitative research method was used in the present study, however the data were collected through bibliometric analysis. The SPSS software was used for the analysis of the data, and frequency and percentage analyses were preformed for the data obtained by the bibliometric analysis. Also data were visualized using Tableau's free online data analysis and visualization program (https://www.tableau.com). In the study, 120 academic articles indexed in three databases were found, and all of them were included within the scope of the research.

3.1 The Objective and Significance of the Study

This study purposed to bibliometrically analyze the articles published between 2014 and 2019 by scanning various scientific databases regarding industry 4.0. In this respect, 120 articles published on ScienceDirect, Taylor, and Francis, and Ulakbim/Dergipark scientific databases were collected between 25 September and 13 October 2019, and their bibliometric analysis was carried out in terms of various parameters.

It is considered that this study make a contribution to the productivity and production quality of especially manufacturing sectors and other sectors such as education, information technologies, and health, to raise awareness on the subject and to the literature. It is believed that it fills the gap in the literature in terms of performing the bibliometric analysis between the determined dates of this study, referring to industry 4.0 through three different databases.

3.2 Research Problems

- ✓ In which databases were the journals searched?
- ✓ What were the names of the journals?
- ✓ In which years were the journals published?
- ✓ What were the main themes of the journals?
- ✓ In which fields were the journals published?
- ✓ Were the articles published in the journals previously presented in a scientific meeting?
- ✓ At which scientific meetings were the articles previously presented?
- ✓ What was the number of keywords in the abstracts of the journals?
- ✓ Was the word industry 4.0 existed in the keywords in the abstracts of the journals?
- ✓ Where was the word industry 4.0 existed in the keywords of article abstracts?
- ✓ What was the number of the authors of the articles published in the journals?
- ✓ What were the countries of authors in the articles in the journals?

4. Results

This section contains findings on the analysis of bibliometric data related to industry 4.0 obtained from journals in various databases. The findings are presented in the following tables. Fig 1 shows the the databases where journals are scanned:

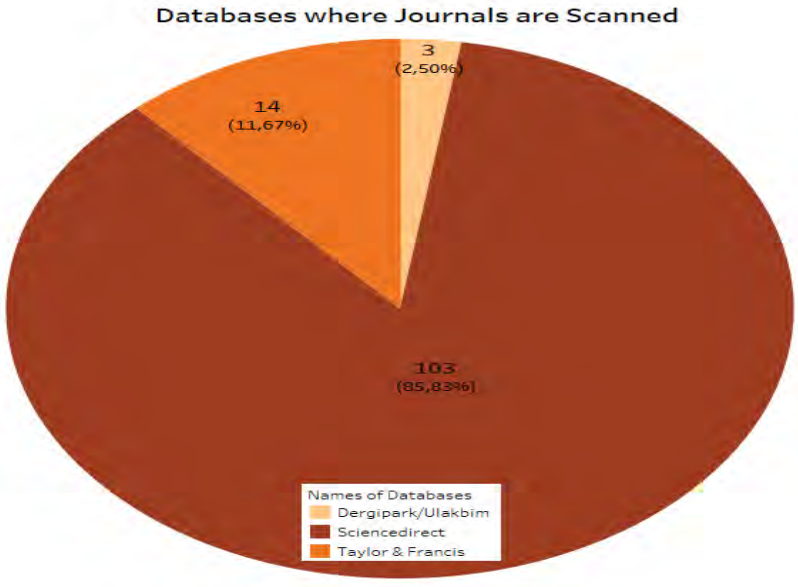

Fig 1. Databases where Journals are Scanned

As shown in the table, it is established that the Sciencedirect database has the highest number of articles (103 articles; 85,8%), which is followed by the Taylor & Francis database (14 articles, 11,7%), and the Dergipark/Ulakbim database (3 articles; 2,5%). The names of the journals scanned in the databases are presented in the Fig 2:

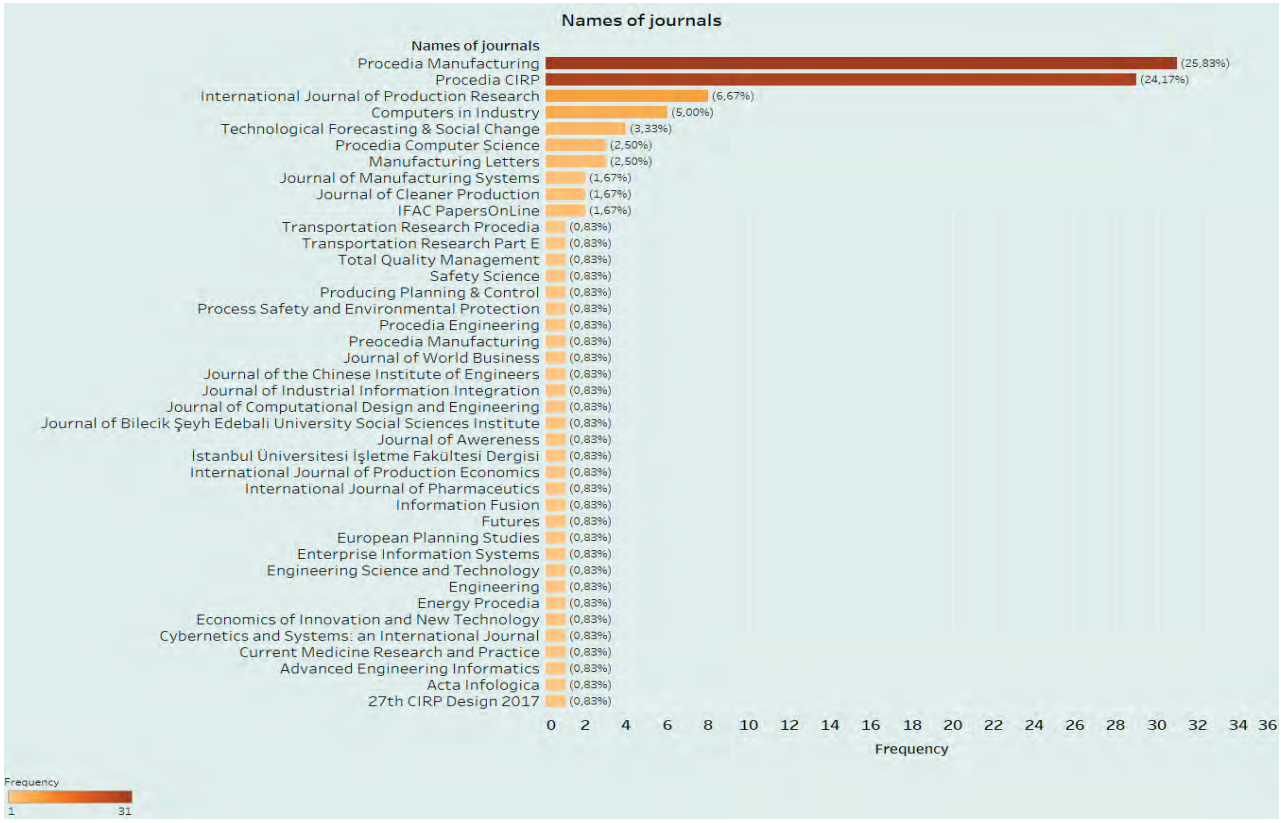

Fig 2. Names of Journals

As can be seen in Table 9, 'Procedia Manufacturing' was in the first place (31 articles; 25,8%), 'Procedia CIRP' was in the second place (29 articles; 24,2%), and 'International Journal of Production Research' was in the third place (8 articles; 6,7%). Fig 3 represents the years of publication of the journals:

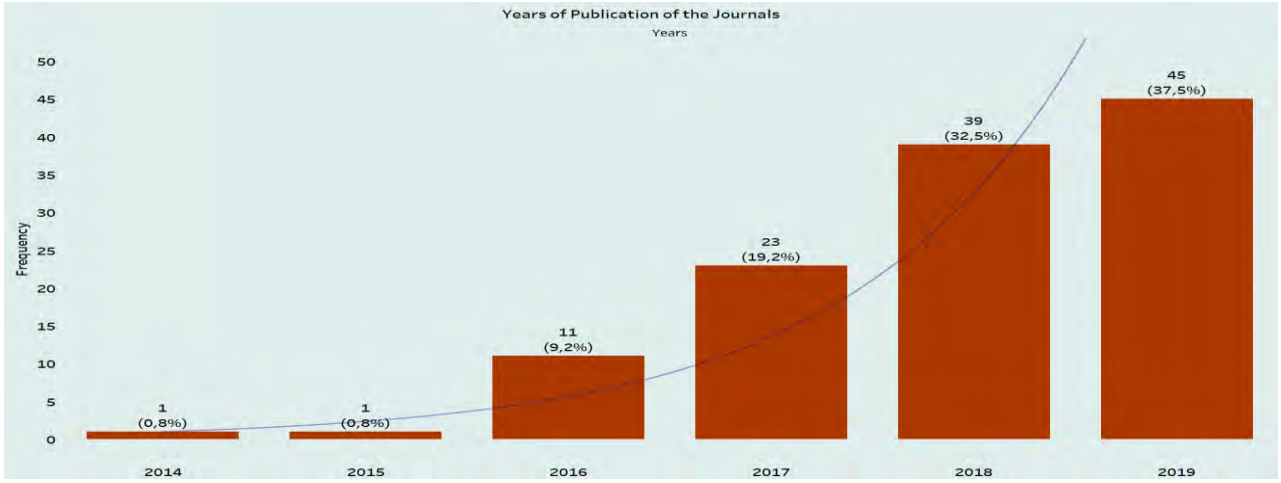

Fig 3. Years of Publication of the Journals

The highest number of articles related to industry 4.0 was published in 2019 (45 articles; 37,5%), followed by 2018 (39 articles, 32,5%) and then by 2017 (23 articles; 19,2%). The main themes of the journals are presented in Fig 4:

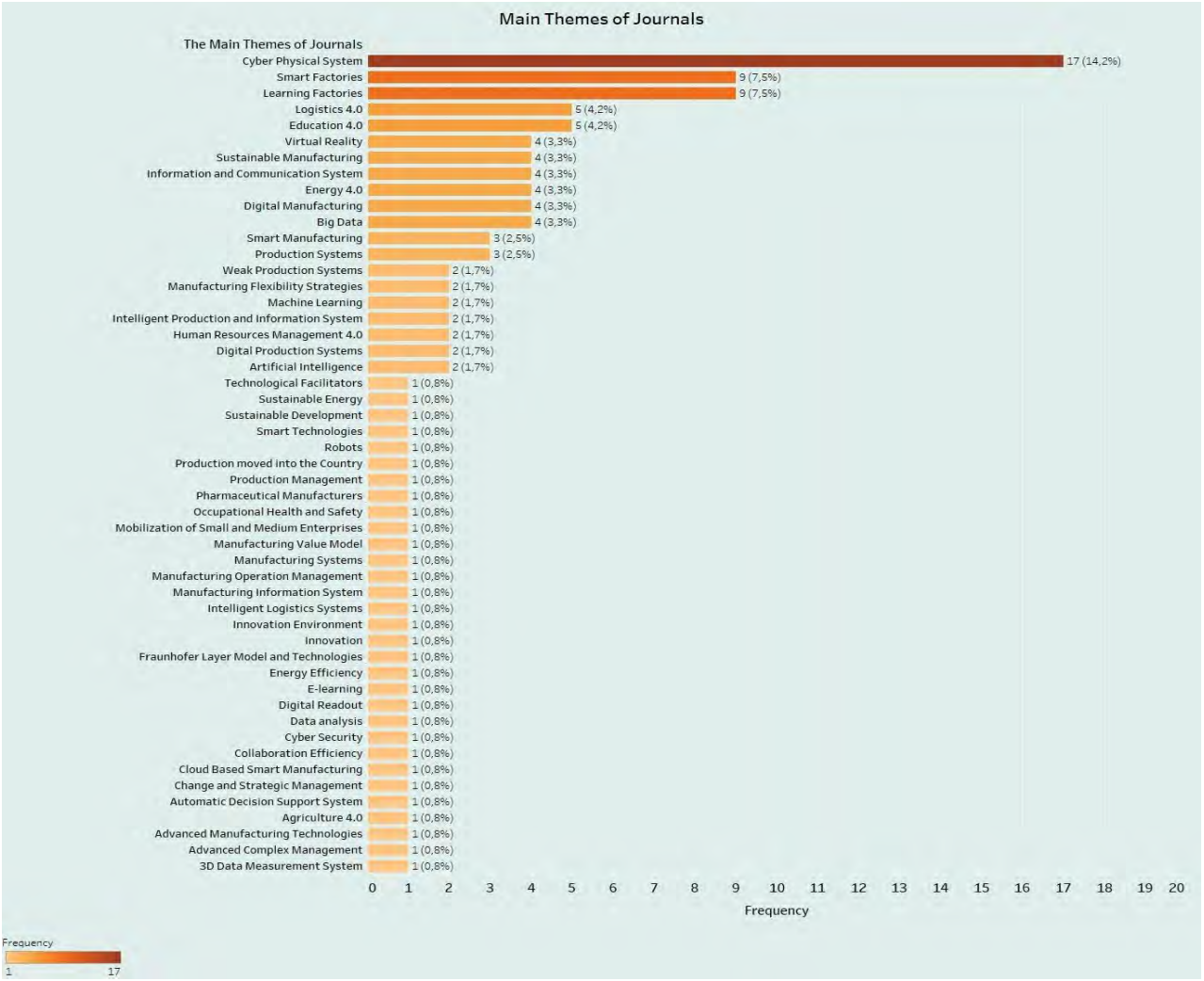

Fig 4. Main Themes of Journals

When the main themes of the magazines are examined, it is seen that the theme named cyber-physical system comes in the first place (17 articles; 14,2%), the main theme named smart factories and learning factories the second place (9 articles; 7,5%), and logistic 4.0 and education 4.0 in the third place (5 articles; 4,2%). The following Fig 5 presents the areas in which the journals are published:

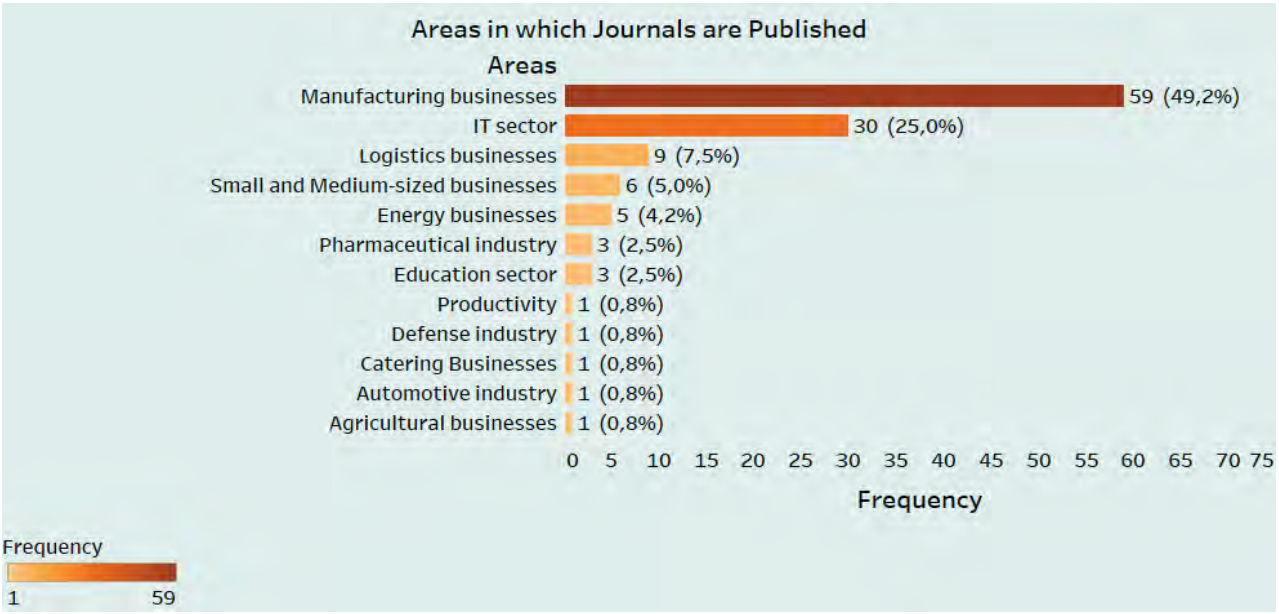

Fig 5. Areas in which Journals are Published

When the areas in which the journals are published are examined, it is seen that manufacturing businesses (59 articles; 49,2%) are in the first location, the informatics sector is in the second location (30 articles; 25,0%), and logistics businesses are in the third place (9 articles; 7,5%). Table 1 below shows whether articles published in journals have previously been presented at a scientific conference:

Table 1. Whether the Articles Published in the Journals have Previously been Presented in a Scientific Conference

Whether articles have previously been presented at a scientific conference	**Frequency**	**Percentage**
Yes	72	60,0
No	48	40,0
Total	120	100,0

As shown in the table, it was established that 72 articles (60%) published in the journals were presented in a scientific meeting, but 48 articles (40%) published in the journals were not presented in a scientific conference. The Fig 6 presents articles on industry 4.0 which were previously presented at a scientific meeting:

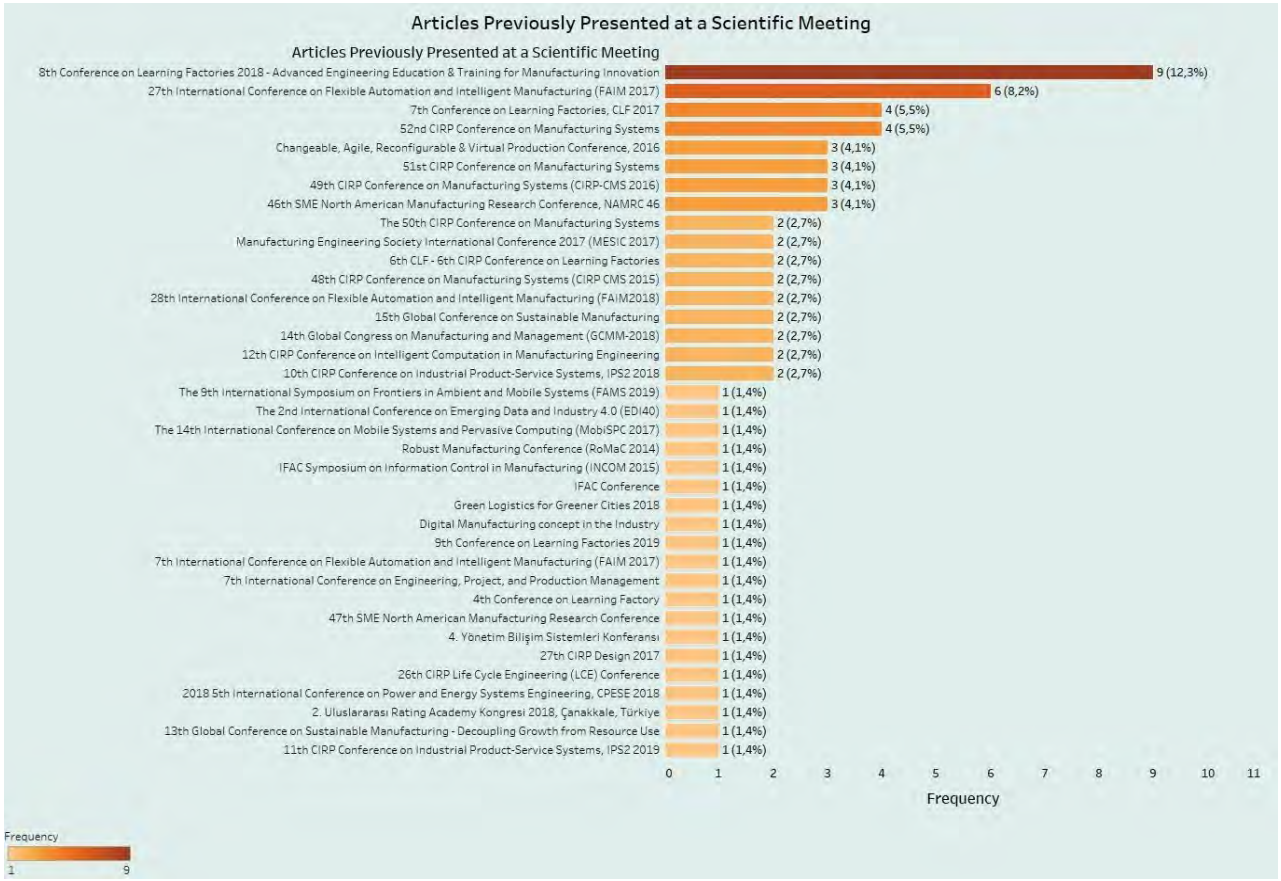

Fig 6. Articles Previously Presented at a Scientific Meeting

When the articles previously presented in scientific meetings were examined, it was found that the scientific conference named '8th Conference on Learning Factories' was in the first place (9 articles; 12,3%), the scientific conferences named '27th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2017)' in the second place (6 articles; 8,2%), '7th Conference on Learning Factories CLF 2017' and '52nd CIRP Conference on Manufacturing System' was in the third place (4 articles, 5,5%). Fig 7 presents the number of keywords in the abstracts of the journals:

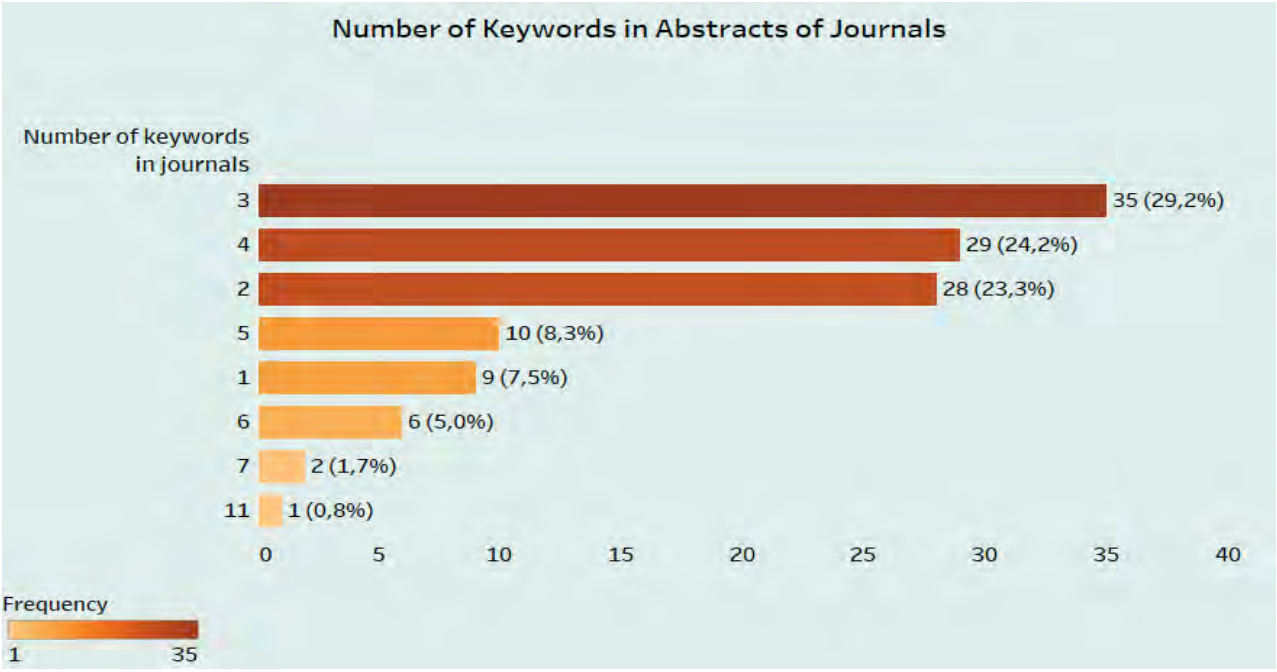

Fig 7. Number of Keywords in Abstracts of Journals

As shown in the Table, it was determined that keywords sections with three keywords were in the first place (35 articles; 29,2%), followed by those with four keywords (29 articles; 24,2%), and those with two keywords (28 articles; 23,3%). Table 2 presents findings as to whether the word industry 4.0 is mentioned in the keywords in the abstracts of the articles:

Table 2. Whether the Word Industry 4.0 is Mentioned in the Keywords in the Abstracts of Articles

Does the keyword include industry 4.0?	**Frequency**	**Percentage**
Yes	97	80,8
No	23	19,2
Total	120	100

As shown in the table above, it was established that the word industry 4.0 was mentioned in the abstracts of 97 articles; 80,8%), while it was not mentioned in the abstracts of (23 articles (19,2%). The following Fig 8 includes where the word industry 4.0 appears in the keywords of the articles:

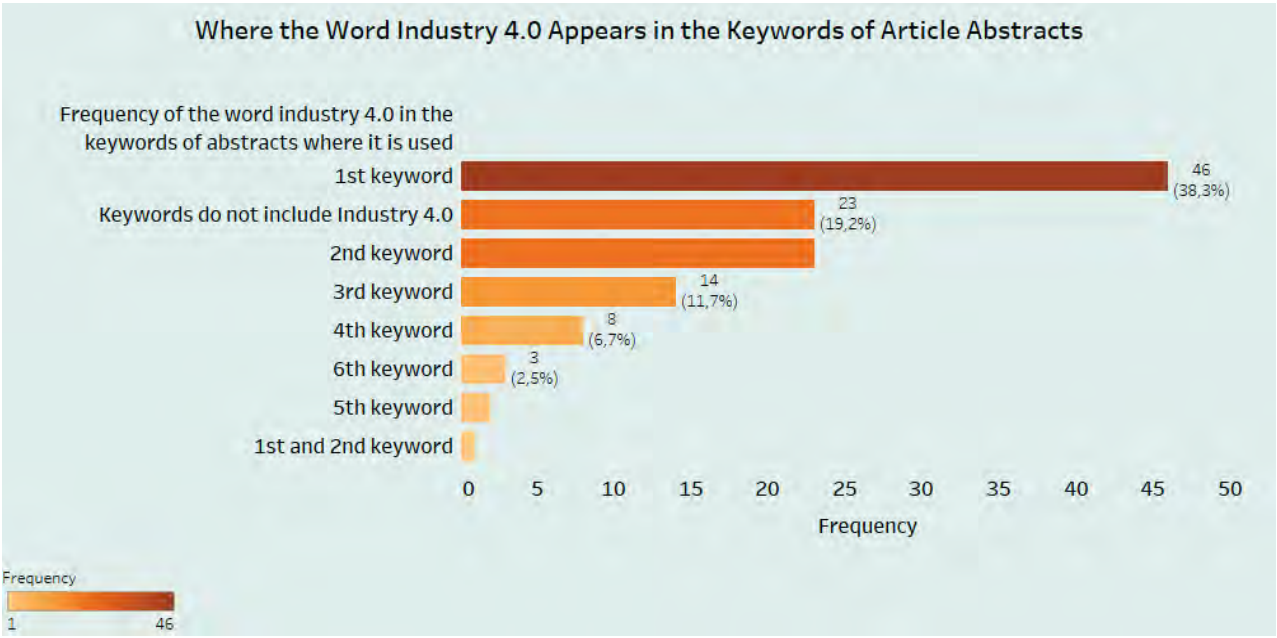

Fig 8. Where the Word Industry 4.0 Appears in the Keywords of Article Abstracts

It was found that the expression industry 4.0 appeared in 46 articles (38,3%) as the first keyword, in 23 articles as the second keyword (19,2%), and in 14 articles (11,7%)) as the third keyword. Fig 9 shows the countries of origin of the authors in the journals related to the research:

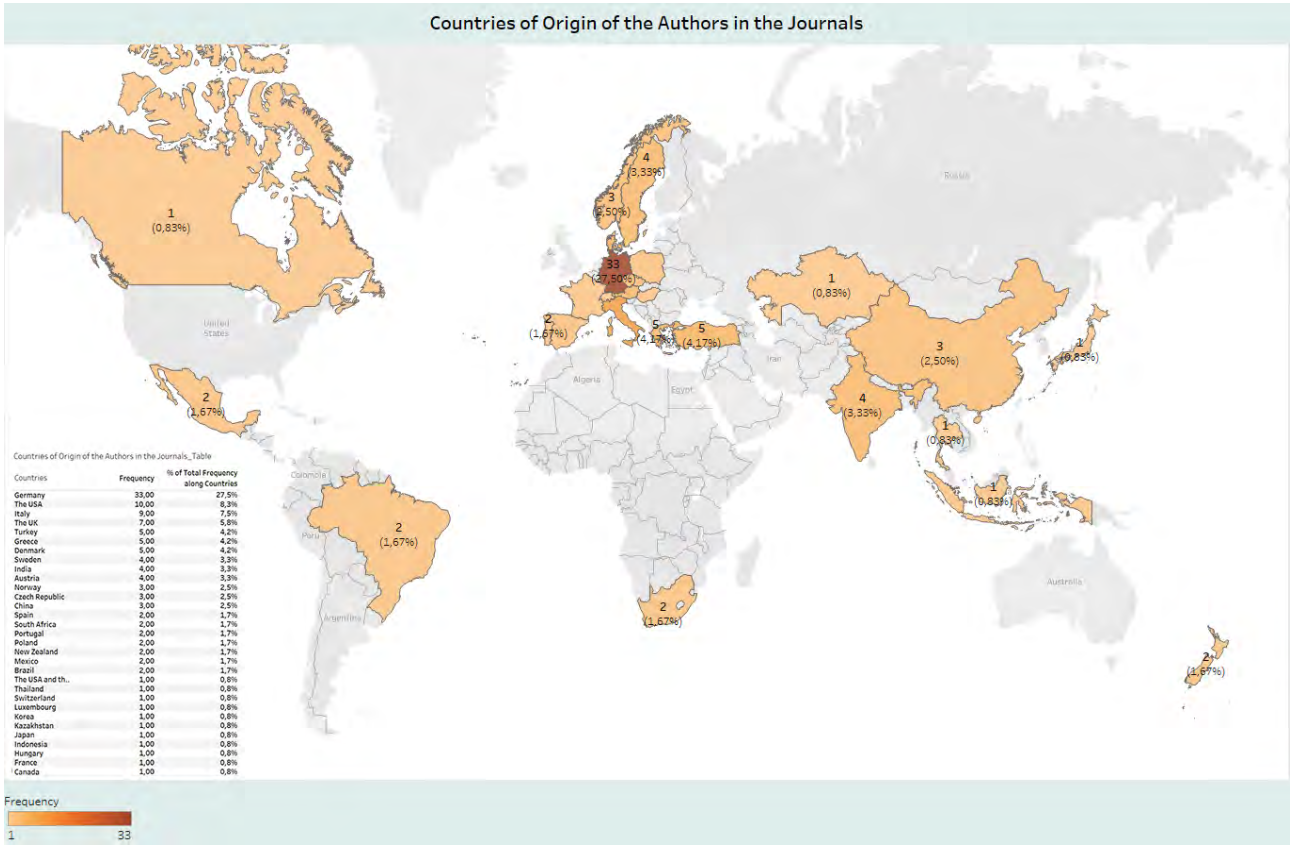

Fig 9. Countries of Origin of the Authors in the Journals

As shown in the table above, it was assigned that the highest number of journal authors were from Germany (33 authors; 27,5%), which was followed by the USA (10 articles; 8,3%), and then Italy (9 articles; 7,5%). The number of the authors in the journals are shown in the Fig 10:

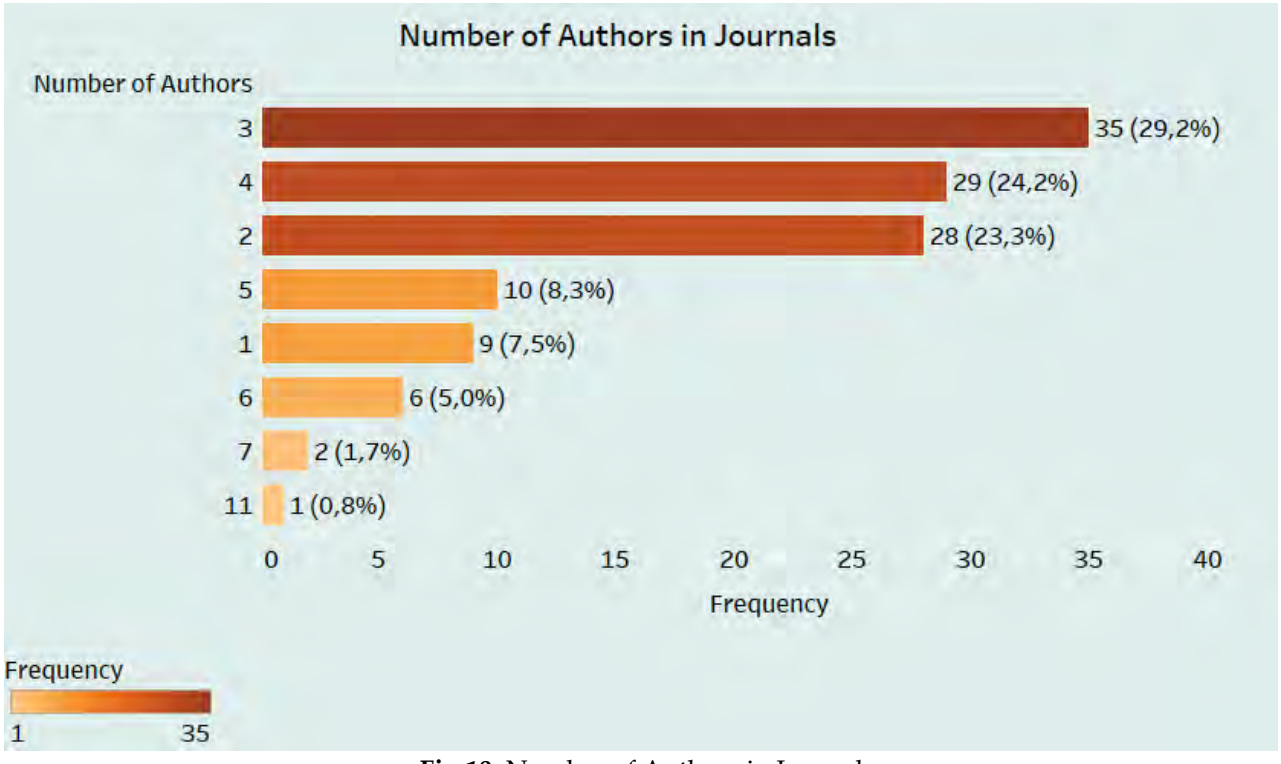

Fig 10. Number of Authors in Journals

When the number of authors in the journals is examined, it is seen that three-author articles (35 articles; 29,2%) are in the first place, and four-author articles (29 articles, 24,2%) are in the second place and two-author articles (28 articles; 23,3%) are in the third place.

5. Conclusion, Discussion, and Recommendations

Industry 4.0, also known as the smart production and smart factory, is the beginning of an era that allows the intensive use of artificial intelligence technologies in the industrial field. Although the emergence of this technological revolution is related to technical/engineering sciences, its scope affects many academic disciplines such as health, tourism, education, logistics, management information systems, and human resources. This concept affects so many disciplines due to the unprecedented pace of the technological development underlying it.

In today's information and technology age, people digitally carry out numerous activities and transactions in their daily and business lives via smartphones, tablets, or computers. Fast and secure shopping via e-commerce sites without going out, students' receiving online education, taking exams through distance education systems, teachers' entering students' grades through online systems, performing banking transactions easily without waiting in line through internet banking, and corresponding through electronic document management systems in many public and private institutions, tracking the personnel information through the management information system, organizing online or video-based in-service training, tracking of cargo shipments and seeing whether they are delivered over the internet through tracking numbers can be given as examples.

This study purposed to examine the articles published in academic journals on industry 4.0 through bibliometric analysis. For this purpose, a total of 120 academic articles indexed in Dergipark/Ulakbim, ScienceDirect, and Taylor & Francis databases were analyzed in terms of certain parameters such as the number of authors in the journals, the databases in which the journals were scanned, the years in which the journals were published, etc. Then, the data collected were tabulated using the SPSS 23 statistical software package in line with the specified parameters, and the tabulated data were interpreted.

When the number of authors in the journals, the databases, names of the journals, and the years of publication were examined, It was determined that the journal that published the most articles on industry 4.0 in 2019 was Procedia Manufacturing that is indexed in the Sciencedirect database, and three-author articles were published most. In this respect, it can be concluded that as the journal focused on publications related to manufacturing in 2019, and the importance of the subject was understood, the productivity of the authors increased that year. Accordingly, the results obtained in the present study regarding the names of journals is similar to the findings of the studies conducted by Zabidin et al. (2020). The results about the publication years of of the journals is similar to the findings of the studies by Bigliardi et al., (2021) and López-Robles et al., (2020). However, the results about the publication years were not consistent with the findings of the studies performed by Zabidin et al. (2020), Cobo et al. (2018), Tepe ve Ozcan (2021), and Newman et., (2020).

Examination of the country of the authors, the fields in which the journals were published, and their main themes showed that the authors were mostly from Germany, the journals mostly focused on manufacturing businesses, and the main theme was cyber-physical systems. It can be said that these findings are in line with the name of the journal with the most publications and that cyber-physical systems are one of the most important concepts that reveal the basis of the industry 4.0 process. In addition, the authors were mostly from Germany because it was the country where industry 4.0 first emerged. Thus, it can be stated that The results obtained in the present study are partially similar to the findings in the studies by Zabidin et al. (2020), Bigliardi et al. (2021), and Tepe ve Ozcan (2021), Cobo et al. (2018), and Newman et al. (2020).

When the articles are examined as to whether the articles published in the journals were previously presented in a scientific conference and whether the word industry 4.0 was included in the keywords of the article abstracts, it was understood that more than three-quarters of the articles published in the journals were previously presented in a scientific conference. The word industry 4.0 was used in almost all the keywords sections of the abstracts. In addition, it was determined that the articles in the journals were

mostly presented at the scientific conference named '8th Conference on Learning Factories 2018-Advanced Engineering Education & Training for Manufacturing Innovation', and the word industry 4.0 was the first keyword in most of the keywords sections of the article abstracts. From this, it can be determined that the authors preferred to convert their studies into articles instead of full-text papers in scientific conferences and that the authors used the word industry 4.0 as the first keyword in the keywords of the articles' abstracts emphasize industry 4.0. Accordingly, these results are partially similar to the findings reported in the studies by Zabidin et al. (2020) and Cobo et al. (2018). However, the results are not consistent with the findings of the study conducted by Muhuri et al. (2019).

Industry 4.0 is the effect of the technology that the information society faced after the Industrial Revolution on the industry and then on all business functions. This effect first started in the manufacturing industry and then spread to other sectors such as education, health, logistics, informatics, energy, and security with the domino effect. Hence, it is considered that the present study make a contribution to the sectors that were positively affected by industry 4.0 to act with a focus on innovation to provide efficient, effective, customer-oriented goods and services and to the literature. In addition, investments by businesses in different sectors in research and development activities will contribute to investments in technological developments by putting the innovation-oriented working principle in practice. Businesses understanding the importance of industry 4.0 on a micro-scale will provide long-term benefits to the country's economy at a macro scale by creating a culture and strategy in this direction.

This study is limited in terms of the number of databases included and the year intervals selected. Therefore, the researchers who will conduct bibliometric studies on industry 4.0 in the future are recommended to include more databases and wider year intervals, apply various methods in data analyses, and employ analysis approaches that will evaluate the methods selected. In other words, it can be said that using databases that they can select wider year intervals, applying qualitative and quantitative methods together, and utilizing different qualitative measurement means like scientific and mapping and network analysis can be useful in the studies that they will carry out.

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