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KNOWLEDGE MAPPING OF RESEARCH ON INDUSTRY 4.0: A VISUAL ANALYSIS USING CITESPACE

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Abstract

This study aims to explore thematic networks in research of Industry 4.0 in recent years. The analysis presented in the paper is based on the data retrieved from the Web of Science about publications that included the terms "fourth industrial revolution" and "Industry 4.0" within the domain of business application. The research consisted of a general analysis of publications and a more detailed analysis conducted using CiteSpace. CiteSpace, one of the very popular visual analysis tools for mapping the scientific networks, was used to analyze extracted articles and identify existing networks, clusters, and most influential authors. The findings indicate that Industry 4.0 represents a well-developed research field with distinctive but complementary research topics and also points out the emerging research topics. The study results can be helpful in further research on Industry 4.0 and relating technologies because it indicates the direction of recent research development.

Keywords: Industry 4.0, knowledge mapping, literature review, visual analysis, clusters

1. INTRODUCTION

In recent years, the industry has faced significant market instability and challenges with complex requirements, customization of products and intense global competition. It has become clear that the existing principles of value creation are not sufficient to achieve an adequate level of flexibility and sustainability of business systems. In order to adapt to the dynamics of change and manage to achieve a shorter time to the market response, business systems have turned to digitalization. Industry 4.0 means the latest evolution of technologies and full integration with business-production systems (Dalenogare et al., 2018). Several technologies, on which the digitalization of business-production processes is based, have been developed such as the Internet of

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Things (IoT), cloud computing (CC), Cyber-physical systems (CPS), big data, machine learning and Artificial Intelligence (AI) (Sevinç et al., 2018; Xu et al., 2018; Büchi et al., 2020; Sony, 2020).

One of the leading platforms for digital transformation, "Plattform Industrie 4.0", states: "Industrie 4.0 refers to the intelligent networking of machines and processes for industry with the help of information and communication technology." (https://www.plattform-i40.de/). Industry 4.0 means connecting computers that communicate with each other without human intervention. However, digitization of business-production systems does not mean putting computers at the center of production technology, but a higher level of connection via the global network, surpassing the company and national business boundaries. It is necessary to emphasize: "Industry 4.0 isn't just about investing in new technology and tools to improve manufacturing efficiency- it's about revolutionizing the way your entire business operates and grows." (www.epicor.com)

Industry 4.0 suggests incorporating advanced technologies in all life and business activities which can lead to new challenges for companies and society. Along with Industry 4.0, the paradigm of business sustainability was developed, which is striving to establish environmentally, economically and socially acceptable production and consumption (Khanzode et al., 2021). The radical changes brought by Industry 4.0 are marked as significant chances for the integration of sustainability and ecology with production throughout the whole value chain (Lu et al., 2020). The emergence of Industry 4.0 and its extensive implications have drawn attention to several segments that need to be addressed.

Recently, Industry 4.0 has received considerable attention from researchers. Numerous studies have addressed Industry 4.0 and related technologies using different approaches (Liao et al., 2017; Lopes de Sousa Jabbour et al., 2018; Xu et al., 2018; Tao et al., 2019). However, a systematic review of the literature using bibliometric research of sources on Industry 4.0 has not been conducted so far. Also, in previous works, there has been no comprehensive structuring of recent literature and the impact that some sources have on the development of knowledge about Industry 4.0. In this paper, the main goal is to thoroughly examine the literature from the Web of Science Core Collection database and perform the mapping. For this purpose CiteSpace software for bibliometric analysis is used. In this way, networks of occurrence of common terms can be analyzed and clusters identified. The study will enable the determination of Industry 4.0 research progress and directions. The following questions will be answered through the research:

-How did the research in the field of Industry 4.0 develop chronologically?

-What are the most influential authors and articles?

-How keyword-based industry 4.0 knowledge networks are structured?

2. THEORETICAL BACKGROUND

Industry 4.0 originated from an initiative to make the German manufacturing industry more competitive globally (Sommer, 2015). The evolution of information and communication technologies and unstoppable trends in wireless networking have inevitably struck the industry and resulted in the development of complex Cyber-Physical Systems. In order for the German economy to remain a leading competitor in a fiercely competitive environment and adequately respond to global environmental and energy challenges, working groups had been formed, and numerous analyses and plans had been made (Kagermann et al., 2013). Soon, the governments of many countries and the most influential international companies and organizations included in their development strategies the accelerated integration of innovative technologies and industries (Liao et al., 2017; Li, 2018). This interest has made the fourth industrial revolution one of the most prominent themes of recent years.

Industry 4.0 is built on several complementary technologies. The Internet of Things (IoT) is driving technology for Industry 4.0 (Xu et al., 2014). Via IoT, production machines are connected to other network devices, allowing valuable data collection with minimal human involvement for further analysis and establishing smart factories. In order to fully realize smart production, it is necessary to connect the entire business chain, from engineering, through supply, production, sales, distribution and, finally, provision of services. Hence, what distinguish cyber-physical systems from mere information technology is the horizontal and vertical integration of the business system in CPS and its ability to interact with physical systems in real-time (Boyes et al., 2018).

Cognitive computing techniques, data science, and analytical models have been used to analyze a vast quantity of data in real-time to realize smart manufacturing opportunities (Chen et al., 2018; Xu et al., 2018). This integration is possible by establishing cloud computing that stores and processes large amounts of data. Cloud computing enables recourse sharing, dynamic allocation and flexible extension timely and user friendly (Büchi et al., 2020; Židek et al., 2020). Using cloud computing is helpful for enterprises because it allows them to scale the needs of their business properly and thus achieve significant savings. After collecting and storing data from all phases of the business-production system, artificial intelligence (AI) and machine learning provide key answers about the company's operations. Namely, using these technologies based on big data analysis creates learning algorithms, increases visibility, predictability, and enables business process automation. Increasingly stringent requirements demand that changes in production occur in real-time, so it is necessary to analyze the data where they are created. Javaid et al. (2021) emphasized big data as essential for resolving process and quality deviation, energy and resources efficiency and market screening. Also, with big data knowledge supporting, decision-making becomes more accurate, enhancing strategic, operational and marketing performances (Gupta et al., 2021). On the other hand, since artificial intelligence is considered to be in the early stage of life and already notably contributes to productivity growth and has implications on cost reduction, its impact is yet to be expected in the future (Crafts, 2021).

Edge computing advantage is reflected in the fact that data stays close to the source, which, besides speed, increases data security. Cyber security is one of the critical concerns in cyber-physical systems and the ongoing issue of digital transformation and Industry 4.0.

When considering the benefits of digital transformation for production, it is possible to single out the Digital Twin. In the era of Industry 4.0, based on collected data, the product or production process can be virtually replicated. The virtual replication continuously updates from different data sources from real production and it learns (Büchi et al., 2020). Based on extracted knowledge, a virtual model can be utilized to monitor and optimise the production process. As a result, through simulations, productivity and workflow improvements can be made, and new products can be created (www.ibm.com).

Insights.sap.com lists the major benefits of Industry 4.0, such as significant changes in productivity and process automation; resilience and adaptability to changes in the market and the economy; opportunities to test new business models and quickly use the noticed chances; and finally, environmentally friendly and sustainable solutions without sacrificing profits. Although the sustainability literature does not rely on Industry 4.0, the essence of Industry 4.0 technology is overcoming business challenges through more efficient use of resources and changing the status of the workforce through creating highly skilled jobs, which is in line with the triple bottom line concept (Khanzode et al., 2021). Furthermore, Nascimento et al. (2018) conclude that modern technologies can significantly contribute to sustainable production by optimizing flow management throughout the value chain by integrating the principles of circular economy (CE) and Industry 4.0. In one article published by Forbes, it is stated that Industry 4.0 is growing, and at the present moment picture of its possibilities cannot be completed. Still, its potential is widely recognized by companies. In that sense, it is pointed out the importance of upskilling the employees to adequately respond to Industry 4.0 challenges (Marr, 2018).

Sony (2020), on the other hand, pointed out the major cons of Industry 4.0: the deficiency of highly skilled labor, resistance to company changes, and emerging social consequences. In addition, cyber security and high initial costs are stated as serious drawbacks for introducing new technologies. Also, the negative impact of data sharing in a competitive environment is marked as a significant con element. Similar barriers were established by Khanzode et al. (2021). Except the previous, it was found that additional obstacles for small and medium enterprises are the upgrade of technologies and difficult access to the necessary financial resources.

To date, Industry 4.0 has the most significant impact on large business production systems, making their operation more flexible, optimal, customer-oriented, and economically more justified. Contrary, small and medium-sized enterprises face significant delays in adopting and implementing new technologies in business (Sommer, 2015; Sevinç et al., 2018). However, as Industry 4.0 becomes more mature and technology more robust, real-time information sharing and networking of all parts of the value chain will become commonplace in all industry sectors.

With all previously stated in mind, to achieve Industry 4.0 benefits, a substantial shift in the digitalization of business is needed. Developing an agile mindset of management structures and employees is required to fully integrate information and communication technologies in the business-production system (Abdollahbeigi & Salehi, 2020). Necessary structural changes often mean defining a new business strategy. The organization need to be transformed to take advantage of new opportunities through strong product differentiation, personalized services, market segmentation, dynamic pricing, and strong customer relationships (Porter & Heppelmann, 2014; Sony, 2020). In order to successfully implement Industry 4.0, several management methods have been defined, such as Enterprise Application Integration (EAI), Service-oriented architecture (SOA), Business Process Management (BPM), etc. (Xu et al., 2018). These methods enable the synchronization of virtual and real flows in business-production systems based on agile, intelligent and networked value chains (Moeuf et al., 2018).

Recognizing the complexity of Industry 4.0 and its wide prevalence, there is a need for comprehensive topic research and analysis of literature sources in order to evaluate existing knowledge. It is necessary to consider the technological and social challenges of Industry 4.0, but also the scientific challenges in mapping such a diversified topic cannot be ignored.

3. DATA AND RESEARCH METHOD

The Web of Science (WoS), produced by Thomson Reuters, is an important tool for indexing the scientific literature that provides researchers with a comprehensive insight into the research flows in relevant scientific fields. In addition, the Web of Science is also often used for bibliometric analysis (Zhang et al., 2020; Azam et al., 2021; Wang et al., 2021). In order to achieve the representativeness of the literature sources used in the analysis, the focus was placed on the Web of Science Core Collection database.

The first phase in generating a database for analysis is the selection of appropriate literature sources. The first keyword in the Web of Science Core Collection database search was "Fouth Industry revolution". The search determined that the first article, which refers to the fourth industrial revolution, was published in 2003 entitled "The world and business computing in 2051" by author Chandra S. Amaravadi. The author predicted the evolution of energy sources, genetics, space research and information technology. The globalization that the world was facing at that time conditioned the need to unify bureaucracy, trade and personal identification, which was realized through the implementation of technology.

The term "Industry 4.0" in the context of industrial application is mentioned in work "Industry 4.0: A Best Practice Project of the Automotive Industry" by Franz E. Gruber, 2013, whose topic is the application of Factory Framework T production software technology for shop floor management.

Accordingly, the time span considered in the study refers to the period 2013-2021. Since the aim of the paper is to map the literature related to the application of Industry 4.0 in business, the categories selected to refine the literature are Engineering industrial, Engineering manufacturing, Management, Computer science information systems, Computer science interdisciplinary Applications, Operation research management science, Business, Business finance, Ethics, Economics, Green sustainable science technology, and Social issues. Only articles from scientific journals were taken as reliable and high-quality sources for knowledge mapping. Book reviews, proceeding papers, editorial letters, news items were excluded from the search in order to eliminate the unnecessary accumulation of literature sources that are not relevant to the research area.

A search of both the terms "Fouth Industry revolution" and "Industry 4.0" simultaneously, with the application of the above restrictions, yielded 4053 results from the Web of Science Core Collection. After a thorough review of titles and abstracts, several publications that did not belong to the research topic were considered irrelevant and removed. In the end, the database resulted in 2428 articles, and this database was used further in the analysis. Selected publications meet the requirements of this research. First, selected papers deal with specific technologies of Industry 4.0. Second, the papers relate to the impact and application of Industry 4.0 in business.

The data used in this study were downloaded on December 30, 2021, from the Web of Science. CiteSpace, a visual analytical tool proposed by Chen (2010), was used for analyzing the obtained extensive database. Using data mining techniques, Cite Space software finds structures, interactions and clusters in specific scientific fields and enables the analysis of trends in research.

4. RESULTS

4.1. Basic situation analysis

In the paper, 2428 publications published between 2014 and 2021 were analyzed. Using Pareto analysis, it is concluded that the number of publications increased in this period. In the initial period (2014-2016), when Industry 4.0 was acquiring its place in publications on business applications, only 1.57% of the total number of papers was published. Following the acceptance of Industry 4.0, greater interest from scientists occurred therefore 16.68% of the total number of papers were published in the period 2017-2018. The literature on Industry 4.0 has amplified in recent years (2019-2021), with 81.75% of the total published papers (Figure 1).

When looking at the Web of Science Categories, most publications are within the topics of Management, Engineering Industrial and Engineering Manufacturing, followed by Operations Research Management Science, Computer Science Information Systems and Computer Science

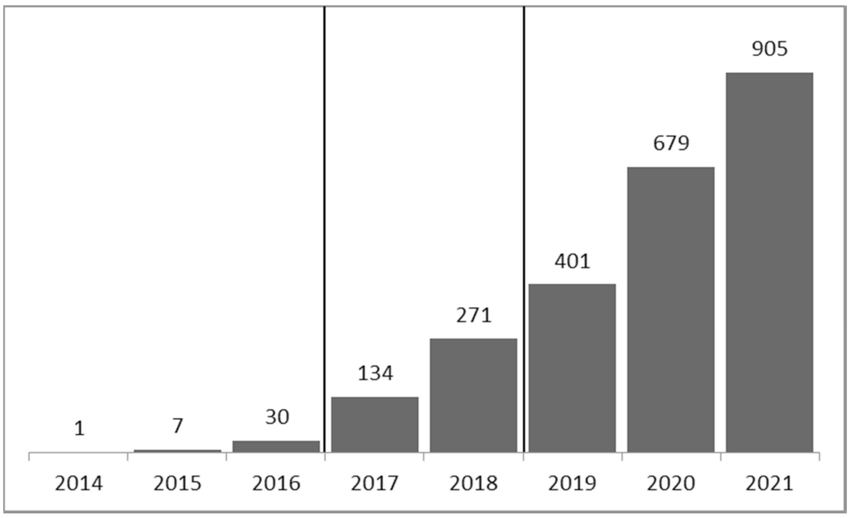

Figure1. Annual distribution of the studies on Industry 4.0 from WoS

Interdisciplinary Applications (Figure 2).

The initial database obtained from the Web of Science was also used to analyze the most cited articles. As a result, the 20 most cited articles have been identified and presented in Table 1. 45% of the selected publications are literature reviews related to various innovative industries 4.0 and indicate the wide distribution of the topics.

4.2. Mapping knowledge using CiteSpace

A more detailed analysis of literature sources is performed using CiteSpace. The author of CiteSpace, Chen (2010), states that the basis of the analysis of publications is the modeling of the knowledge domain and focusing on the issues addressed by the researchers as well as the methods and tools they used.

The collaboration between states in Industry 4.0 research is shown in Figure 3. Each node represents the country, and the size indicates the number of published papers. The analysis of the co-author network shows that Peoples R. China is the country with the most significant number of publications (142 articles) in a considered set of data, which is represented by the largest circle in the figure. In addition, Italy (132 articles), England (103 articles), the USA (102 articles), and Germany (83 articles) also have a significant share in the number of publications. The result indicates an essential role of these countries in the development of Industry 4.0 research. Also, nodes that have pronounced outline circles suggest that states have significant research connections with many other states in the network.

Co-citation cluster analysis makes it possible to determine the most influential papers in Industry 4.0 research and future research directions. Data obtained from Citespace show that 934 records were analyzed that corresponded to the given period 2014-2021. The analyzed references were cited 47,408 times. The analysis

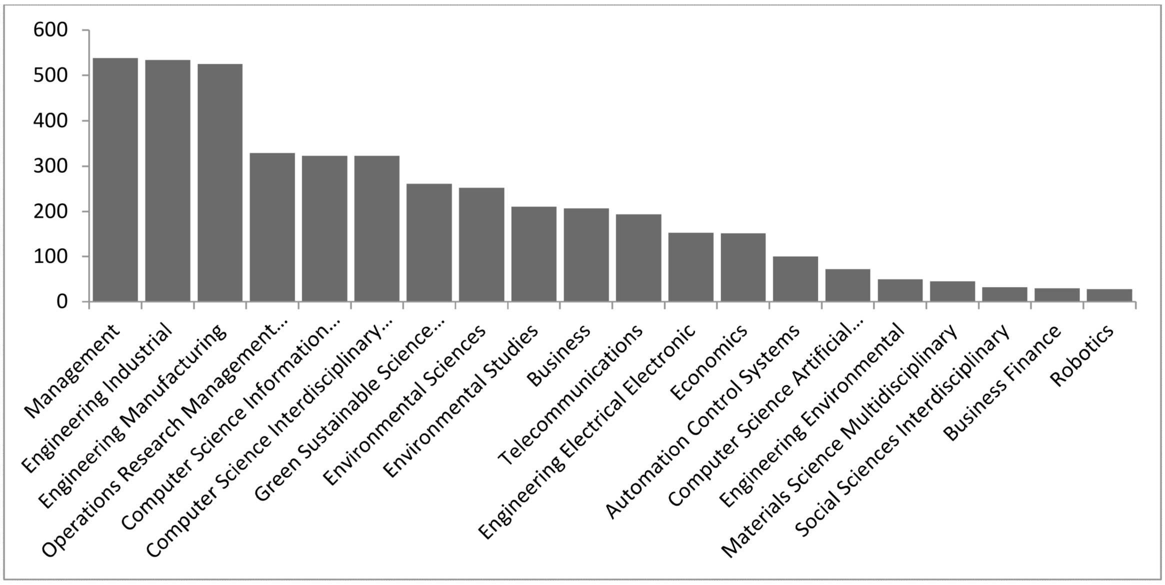

Figure 2. Categories distribution of the studies on Industry 4.0 from WoS

Table 1. 20 most cited articles from WoS

No.	Article Title	Authors and publication year	Cited, WoS Core
1	Industry 4.0: state of the art and future trends	Xu et al., 2018	813
2	Cyber-physical systems in manufacturing	Monostori et al., 2016	639
3	Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal	Liao et al., 2017	635
4	Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination	Wang et al., 2016	541
5	Industry 4.0 and the current status as well as future prospects on logistics	Hofmann & Rüsch, 2017	538
6	Industrial Internet of Things: Challenges, Opportunities, and Directions	Sisinni et al., 2018	448
7	Industry 4.0 technologies: Implementation patterns in manufacturing companies	Frank et al., 2019	435
8	Understanding the implications of digitization and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry	Oesterreich &Teuteberg, 2016	382
9	The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics	Ivanov et al., 2019	346
10	The expected contribution of Industry 4.0 technologies for industrial performance	Dalenogare et al., 2018	343
11	Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison	Qi & Tao, 2018	334
12	Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges	Chen et al., 2018	317
13	Digital Twin in Industry: State-of-the-Art	Tao et al., 2019	313
14	The future of manufacturing industry: a strategic roadmap toward Industry 4.0	Ghobakhloo, 2018	305
15	The industrial management of SMEs in the era of Industry 4.0	Moeuf et al., 2018	298
16	Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing	Tao & Zhang, 2017	288
17	Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations	Lopes de Sousa Jabbour et al., 2018	277
18	The industrial internet of things (IIoT): An analysis framework	Boyes et al., 2018	277
19	China's manufacturing locus in 2025: With a comparison of Made-in-China 2025 and Industry 4.0	Li, 2018	277
20	Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Müller et al., 2018	275

established the existence of 12 clusters based on keywords that appear in titles and abstracts. Based on these clusters, a knowledge map for Industry 4.0 image was identified and presented in Figure 4.

The network is divided into 12 dominant co-citation clusters. The clusters are summarized as follows (Table 2).

The silhouette score represents the cluster homogeneity, which means the higher the silhouette value, the more consistent the cluster members are. Label LLR were obtained using the logarithm likelihood ratio test to select labels that can best represent the central theme of a cluster (Chen, 2006).

The largest cluster (ID # 0) has 77 members and is labeled as a "business model innovation perspective". A silhouette value of 0.74 is the lowest, but this is considered a relatively high level of homogeneity (Chen, 2017). The most influential references in the cluster are Frank et al. (2019), with citation

Figure 3. Visualized network map of the country analysis

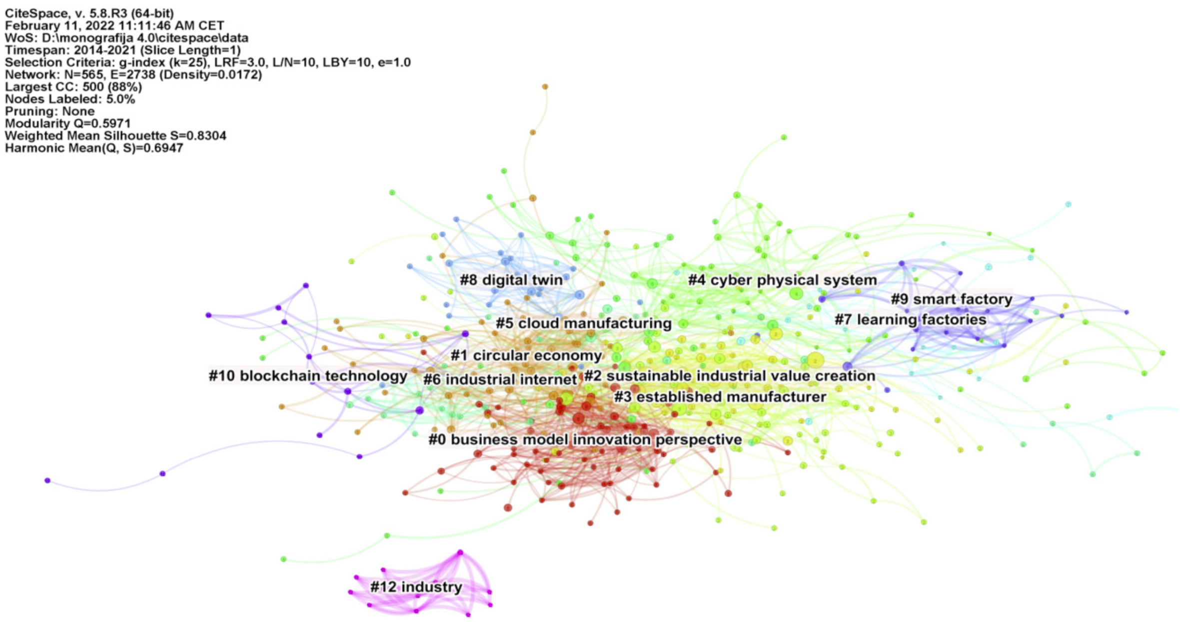

Figure 4. Keyword clustering of the literature on Industry 4.0

counts 59, then Porter & Heppelmann (2014) with citation counts 53, and Dalenogare et al. (2018) with citation counts 46. The authors proposed different patterns in the implementation of technologies of Industry 4.0 in companies. Frank et al. (2019), in order to explain ways for the adoption of new technologies, the proposed framework in which technologies are divided on front-end and base technologies. Base technologies are comprised of data-based technologies responsible for data collection, storage and processing. Front-end technologies are based on the prefix "Smart" in production, products, supply chains and work. A frequently present topic in scientific research is the justification and impact of introducing new business models in operations. Thus, the authors Dalenogare et al. (2018) examined the contribution of Industry 4.0 to business performance and benefits for products, operations and side effects. Changes in business models also condition the disruption of existing value chains and their adaptation to IT infrastructure. Changes are happening at all levels, starting from design, procurement of materials and funding, production, operations, provision of services, all in accordance with the new level of necessary IT security. Due to the fundamental changes taking place in this process, both business strategies and how competitive advantage is achieved in a smart world are changing (Porter & Heppelmann, 2014).

The second-largest cluster (ID # 1) has 72 members and a silhouette value of 0.845. It is labeled as a "circular economy". The most cited papers in the cluster are Lopes de Sousa Jabbour et al. (2018), with citation counts 37, Kamble et al. (2018), and Luthra and Mangla (2018), with citation count 35 each. The cluster connects two challenging trends in terms of implementation, circular economy and Industry 4.0. Namely, the ability of new technological advances based on Industry

Table 2. Details of clusters

Cluster ID	Label	Size	Silhouette	Mean Year	Top terms (log-likelihood ratio, p-level)
0	business model innovation perspective	77	0.74	2017	business model innovation perspective (85.56, 1.0E-4); product firm (85.56, 1.0E-4); enhanced agility (81.66, 1.0E-4)
1	circular economy	72	0.845	2018	circular economy (164.42, 1.0E-4); key resource (107.1, 1.0E-4); energy sustainability (101.99, 1.0E-4)
2	sustainable industrial value creation	69	0.809	2015	sustainable industrial value creation (165.31, 1.0E-4); established manufacturer (152.74, 1.0E-4); multiple case study (126.03, 1.0E-4); triple bottom line (117.86, 1.0E-4)
3	established manufacturer	64	0.726	2016	circular economy (131.08, 1.0E-4); sustainable industrial value creation (87.31, 1.0E-4); established manufacturer (83.91, 1.0E-4)
4	cyber physical system	48	0.874	2014	cyber physical system (210.47, 1.0E-4); current status (195.32, 1.0E-4); smart factory (190.77, 1.0E-4)
5	cloud manufacturing	42	0.835	2014	cloud manufacturing (318.04, 1.0E-4); cloud-based manufacturing process monitoring (126.6, 1.0E-4); smart diagnosis service (126.6, 1.0E-4)
6	industrial internet	32	0.897	2016	industrial internet (162.13, 1.0E-4); manufacturing industry (161.83, 1.0E-4); successful adoption (138.68, 1.0E-4)
7	learning factories	24	0.926	2012	learning factories (137.77, 1.0E-4); future oriented research (137.77, 1.0E-4); industrial user-supplier relationship (129.58, 1.0E-4)
8	digital twin	24	0.886	2017	digital twin (742.33, 1.0E-4); digital twin framework (134.02, 1.0E-4); the-art survey (126.92, 1.0E-4); business innovation perspective (126.92, 1.0E-4)
9	smart factory	22	0.916	2012	smart factory (143.29, 1.0E-4); continuous maintenance (93.78, 1.0E-4); technological challenge (93.78, 1.0E-4)
10	blockchain technology	14	0.978	2018	blockchain technology (220.68, 1.0E-4); product lifecycle management (175.68, 1.0E-4); supply chain management (132.9, 1.0E-4); operations management (129.9, 1.0E-4)
12	industry	12	0.999	2010	industry (48.36, 1.0E-4); global footprint design (32.02, 1.0E-4); perspective (32.02, 1.0E-4)

4.0 to adapt can be used to integrate the circular economy into business practice. The circular economy represents a new paradigm of economic sustainability based on the extension of the life cycle of resources through the processes of maintenance, recycling, and reuse (Machado & Morioka, 2021). The biggest challenge for companies in implementing the postulates of the circular economy is reflected in the company's ability to direct its business operations based on environmental constraints by introducing the ecological aspect throughout the product life cycle (Hrbáčková et al., 2019). Research indicates that the integration of Industry 4.0 technologies is essential for accepting the circular economy and cleaner production, thus achieving real-time data collection and analytics that predict and direct future activities. Industry 4.0 provides alternative approaches to achieving sustainable business and consumption at all levels through shorter production times, increased product quality and better business performance (Kamble et al., 2018; Rajput & Prakash Singh, 2020).

The third-largest cluster (ID # 2) has 69 members and a silhouette value of 0.809. It is labeled as "sustainable industrial value creation". This cluster includes papers with the highest number of citations in network literature analysis. The top-ranked item by citation counts is Lee et al. (2015), with citation counts of 162. The second one is Lasi et al. (2014), with citation counts of 145 and with citation counts of 124 is Kagermann et al. (2013). In the literature, it is possible to find many pieces of research addressing the potential impact of Industry 4.0 and related technologies on sustainability (Khanzode et al., 2010; Khan et al., 2021). Sustainability is currently the leading global concept that presupposes the responsibility of business towards society (Stojanović et al., 2020). Establishing a link between sustainable business practices and the disruptive technologies on which Industry 4.0 is based can be quite challenging nowadays. Significant concerns regarding Industry 4.0 relate to changes in the labor market. Early research estimated that a large proportion of the human workforce would be replaced by machinery, which would lead to the loss of a large number of jobs (Bonin et al., 2015). Therefore, various studies aimed to determine whether implementing corporate social responsibility (CSR) activities focused on employees can balance challenges the Industry 4.0 put in place (Stojanović et al., 2020, 2021). Awareness of sustainable business practices is growing in the business environment spreading throughout the value chain therefore, more and more business strategies focus, in addition to the economic aspect, on the social and environmental aspects of the business (triple bottom line) (Khanzode et al., 2021). The need for sustainability and resource efficiency and adaptation to human needs, in addition to Smart factories and Cyber-physical Systems, are fundamental concepts of Industry 4.0 (Lasi et al., 2014).

The 4th cluster (ID #3) has 64 members and a silhouette value of 0.726. It is labeled as an "established manufacturer". The most cited items are Liao et al. (2017), with citation counts of 101, then Xu et al. (2018) with citation counts of 82 and Zhong et al. (2017), with citation counts of 62. By analyzing the top-ranked articles belonging to the cluster can be concluded that comprised of review articles of industry 4.0 and associated topics concerned with changes in producing industries. The related technologies encompass Cyber-physical Systems, IoT, cloud computing, industrial integration, enterprise architecture, Business

Process Management, and others (Xu et al., 2018).

The remaining clusters relate to the core technologies of Industry 4.0. Cluster 5 (ID # 4), named "cyber physical system" with 48 members, has a silhouette value of 0.874. The most cited paper within the network is Wang et al. (2016), with 75 citations. Cyber-physical system is the core of Industry 4.0, where physical and information components are interconnected and coordinated, enabling adaptability, resilience and safety of production (Xu et al., 2018). Cluster 6 (ID # 5), named "cloud manufacturing", has 42 members and a silhouette value of 0.835. The most influential paper is Monostori et al. (2016), with 59 citations. Cluster 7 (ID # 6) with the name "industrial internet" encompasses 32 articles, has a silhouette value of 0.897 and most cited within the cluster is Xu et al. (2014) with 52 citations. The 8th cluster named "learning factories" (ID # 7) has silhouette 0.926. The most influential paper is Davis et al. (2012) in which the settings of smart manufacturing are defined as necessary prerequisites for benefits in modern production. Cluster 9 (ID # 8), named "digital twin", has 24 members and a silhouette value of 0.886. The most cited paper is Tao et al. (2018). Cluster 10 with the name "smart factory" (ID # 9) has 22 articles and a silhouette of 0.916. Smart manufacturing is the heart of Industry 4.0 implementation. Based on lean as a philosophy not only in the manufacturing process but also in planning and technology, the most influential work in this cluster has been recognized as the work of Zuehlke (2010). Cluster 11 (ID # 10), named "blockchain technology", is a relatively small cluster with 14 members and a silhouette value of 0.978. Ivanov et al. (2019) are the authors of the most influential work in this cluster. The paper examines the impact of digitization on supply chain management and the risk of disruption. Finally, cluster 12 (ID # 12) is named "industry". The cluster encompasses 12 articles with the highest silhouette value of 0.999. The most cited article in the cluster is ElMaraghy et al. (2012).

Considering the obtained results on the most influential items in the research area can be concluded that the digitalization of business processes began long before the name "Industry 4.0" was used. Further analysis obtained the timeline of each cluster, Figure 5. Industry 4.0 research evolved from a field focused on strategic management in manufacturing under the influence of new technologies. The need for structural changes emerged towards embracing adaptation and engineering based on knowledge and information, which is spotted in clusters "smart factory" and "industry" (National Science Foundation, 2007; Westkamper, 2007; Butala et al., 2008). The papers refer to digital models and machines designed to perform operations and communication via virtual networks in real-time (Butala et al., 2008). At that time, the development of new technologies and their impact in all spheres was already evident, and the papers highlight the challenges and opportunities of "cyberinfrastructure" and the changes expected in a working environment. Maturation of technologies and their clear business delineation cause research on specific types of digital technologies used in business operations (Qi & Tao, 2018; Kohtamäki et al., 2019; Frank et al., 2019; Milošević et al., 2021; van der Valk et al., 2021). Also appeared interest in adapting economic, social and economic factors in order to respond the Industry 4.0 impact on today's critical global issues (Dalenogare et al., 2018; García-Muiña et al., 2021; Kamble & Gunasekaran, 2021).

The cluster with the most extended duration is "sustainable industrial value creation" (2009-2020), which is, at the same time, the cluster with the most cited articles. The timeline visualization reveals the cluster development in the period 2013-2019, where high impact contributions with high citation occurred. This cluster deals with topics related to understanding the implications that Industry 4.0 has for different industries and different social concerns. So, this cluster includes papers related to the implementation of information technology in small and medium enterprises (Müller et al., 2018; Khanzode et al., 2021) as well as implementation in specific industries (Oesterreich & Teuteberg, 2016).

The cluster that last appeared in the researched literature is "blockchain technology" in 2016. Some significant restraint related to the implementation of Industry 4.0 relates to data access concerns and ensuring the security of all network users in the value chain. Blockchain technology emerged from the necessity of storing a considerable amount of data with a high level of privacy and access permission only for trusted users (Christidis & Devetsikiotis, 2016). In addition, very current clusters are both "business model innovation" and "circular economy", where, especially lately, a large number of papers and many citations are being noticed indicating the current direction of research Industry 4.0.

5. CONCLUSION

This paper presents a systematic study on contemporary Industry 4.0 research. Many literature sources that make the knowledge

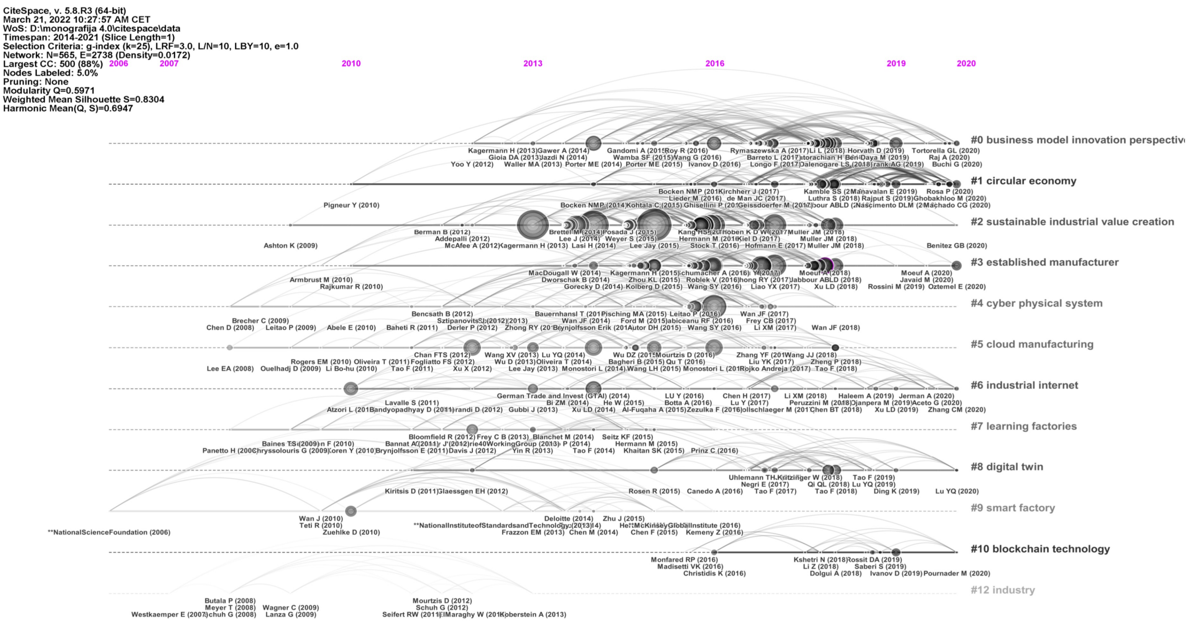

Figure 5. A timeline visualization of the clusters

network in Industry 4.0 research were examined. CiteSpace software was used to explore and present the results, enabling graphical presentation of scientific literature reviews and comprehensive topic analysis. In this way, a contribution has been made to existing literature reviews, as most research is based only on specific aspects of Industry 4.0. Furthermore, the co-citation analysis conducted in the study made it possible to determine the papers that are the most cited and most influential in Industry 4.0 research, following the evolution of research, current trends and anticipation of future research directions.

Research related to the integration of new technologies and production appeared long before the terms "fourth industrial revolution" and "Industry 4.0" appeared and became some of the most relevant terms in the business literature today. In later research, in addition to the increased number of research, there is also a diversification of topics following the development of various technological and information solutions applied in production. The results revealed that the research topic is divided into 12 interrelated but distinct clusters. In addition, there is noticed a shift in research towards business topics representing leading business philosophies such as sustainability and the circular economy. Also, it is determined some emerging technologies have high positions in recent studies. The study can be useful to academics and practitioners for further research as well as for developing appropriate strategies for Industry 4.0 implementation.

As certain limitation of the study, it can be noticed that co-citation analysis has its basis in the citation of individual articles therefore, the importance of newer articles, which still do not have a large number of citations, can be overlooked. Additional analysis can be directed towards splitting literature by years and analyzing the articles with growing citation trends in further studies to overcome this limitation.

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МАПИРАЊЕ ЗНАЊА О ИСТРАЖИВАЊИМА ИНДУСТРИЈЕ 4.0: ВИЗУЕЛНА АНАЛИЗА ПОМОЋУ „CITESPACE“

Анђелка Стојановић

Извод

Ова студија има за циљ да истражи тематске мреже у истраживању Индустрије 4.0 последњих година. Анализа представљена у раду заснована је на подацима преузетим са „Web of Science“ о публикацијама које су обухватале појмове „четврта индустријска револуција“ и „Индустрија 4.0“ у домену пословне примене. Истраживање се састојало од опште анализе публикација и детаљније анализе спроведене коришћењем „CiteSpace“. „CiteSpace“, један од веома популарних алата визуелне анализе за мапирање научних мрежа, коришћен је за анализу издвојених чланака и идентификацију постојећих мрежа, кластера и најутицајнијих аутора. Налази указују да Индустрија 4.0 представља добро развијено истраживачко поље са карактеристичним, али комплементарним истраживачким темама и такође указује на нове истраживачке теме. Резултати студије могу бити од помоћи у даљим истраживањима о Индустрији 4.0 и сродним технологијама јер указују на правац развоја новијих истраживања.

Кључне речи: Индустрија 4.0, мапирање знања, литературни преглед, визуелна анализа, кластери

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