



Industry 4.0 in Healthcare: A systematic review

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ABSTRACT

Healthcare 4.0 has changed dramatically over the last century. It is evolving daily, with physicians and researchers alike developing new tools and strategies. This study analyzes the impact of Industry 4.0 on healthcare (IHC) systems. Therefore, using PRISMA 2015, a systematic literature review was undertaken utilizing articles retrieved from Scopus and Web of Science. A bibliometric and qualitative assessment of 346 and 47 articles was performed. An IHC framework was developed considering the following components: scheduling problems, security issues, COVID-19, digital supply chain, blockchain technology, and artificial intelligence. The study found that during COVID-19, healthcare, and Industry 4.0 fused and evolved together, addressing issues including data security, resource allocation, and data transparency. IHC enables a variety of technologies, including the internet of things (IoT), blockchain, big data, cloud computing, machine learning, and information and communication technologies (ICT), to track patient records and contribute to the reduction of social transmission of COVID-19.

1. Introduction

Manufacturing companies are increasingly conscious of the need to increase their production and efficiency. To do this, they rely on new technology to reduce expenses and increase revenues. Industry 4.0 is a frequently used phrase to refer to this growing usage of technology (Hofmann & Rüsch, 2017). It is also referred to as "the fourth industrial revolution." The term "Industry 4.0" was introduced during the 2011 CeBIT forum conference by some German researchers (Majstorović et al., 2018). It has since become one of the most widely used terms to refer to a process that enables factories and businesses across all industries to interact with internet technologies such as cloud computing, big data, cyber-physical systems, 3D printing, and, more recently, Artificial Intelligence (AI), robotics, additive manufacturing, machine learning, and other advanced tools.

Industry 4.0 is the industrial revolution (Gorecki, Possik, Zacharewicz, Ducq, & Perry, 2021) since the introduction of electricity to factories in the 19th century and Internet technology to business in the 90s. The digitization of business processes and the Internet of Things (IoT) have already started transforming the world of manufacturing, logistics, and supply chain management (Manavalan & Jayakrishna, 2019); however, healthcare has been lagging behind in terms of digitalization and innovation (Golinelli et al., 2020). Thanks to the proliferation of mobile devices and medical instruments, healthcare technologies can now connect and exchange data with each other on an unprecedented scale (Y.-K. Chen, 2012). The healthcare industry

has made several major transformations over the past few decades, from introducing vaccines and antibiotics to creating patient-centered care and now to next-generation genomic medicine (Gubbins et al., 2014). At each stage in this evolution, we have seen an explosion of innovation that changed how patients and providers interact with one another.

As the establishment of tools grows, healthcare systems experience radical modifications and technical specifications concerning industry 4.0 (K. Kumar, Zindani, & Davim, 2019). Industrial revolution 4.0 or, in short, IR 4.0 emerges significantly during the onset of COVID-19. Factors such as social distancing and lockdown in various nations significantly affected almost every country's economy and industrial domain (Anjum et al., 2020; Ahsan, Nazim, Siddique, & Huebner, 2021). As a result, a compulsory merger of IR 4.0 was observed more during the onset of COVID-19 years compared to previous decades. The deadly COVID-19 brings forth many healthcare lacking worldwide, and many countries like Bangladesh, India, the USA, and the UK failed to facilitate healthcare systems appropriately (Ahsan, Ahad, et al., 2021; Ahsan, E Alam, Trafalis, & Huebner, 2020; Ahsan, Gupta, et al., 2020).

However, technological advancement plays a vital role during this pandemic. In order to keep up with the demands of their patients, many healthcare professionals are turning to new technologies, including mobile apps and remote monitoring, to improve the quality of patient care they provide. For example, telemedicine allows nurses and physicians to reach patients in rural or isolated areas who might otherwise have trouble finding adequate medical care, while wearable technology

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helps to monitor cardiac conditions (Ahsan, Mahmud, Saha, Gupta, & Siddique, 2021) and other ailments over time. These new tools allow for more efficient services that can provide medical services for distant residents and reduce the loads on the hospitals and emergency rooms (Mustapha, Khan, Qureshi, Harasis, & Van, 2021).

The advent of COVID-19 and the adoption of IR 4.0 in healthcare generates various directions. Therefore, there is a need to integrate all those directions in a nutshell. Considering this opportunity into account, this study aims to conduct a systematic review of recently published literature that concentrated on two key factors: healthcare and Industry 4.0. The literature on Industry 4.0 in healthcare (IHC) is expanding at an exponential rate (see Fig. 2), highlighting the need to transmit new insights and directions based on the most current advances in the existing research. Thus, 346 publications were analyzed bibliometrically to answer the following study questions: who are the notable authors? What is the current trend in publishing? What are the most influential journals? Which countries, institutions, and topics make the most contributions? Furthermore, from which essential concepts may the extant IHC literature be classified?

Furthermore, in order to provide some insight into IHC, the study intended to answer the following questions using 47 referenced literatures:

- 1 What are the most important applications of Industry 4.0 in healthcare?
- 2 What are the current Industry 4.0 challenges and constraints in healthcare?
- 3 What are the potential future applications of Industry 4.0 in healthcare?

It should be noted that all 47 references were retrieved using the inclusion criteria as outlined in Section 2. The remainder of the section is organized as follows: Section describes the bibliometric study based on the relevant literature, and Section 4 presents the IHC find-

ings. Section 5 summarizes the general findings and offers some suggestions for future study and practice areas for researchers and practitioners. Finally, Section 6 concludes the overall findings with potential remarks.

2. Methodology

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Turrini et al., 2017) is a prominent and extensively used approach for presenting a systematic review (Moher et al., 2015). This study reported on a PRISMA-based systematic literature review (SLR). Paper searching, screening, and selection were carried out in accordance with the PRISMA 2015 guidelines, as indicated in Fig. 1. The first search was conducted using two major datasets: Scopus and Web of Science (WOS). Many scholars and practitioners rely on Scopus and WOS databases for locating quality articles and SLR (Ahsan and Siddique, 2022b; Mustapha et al., 2021; Ahsan and Siddique, 2022a). To keep the study aim more focused and key oriented, we used the Boolean operator with "health" and "Industry 4.0" during the initial search, yielding 869 articles from Scopus and 378 articles from WOS. When the article is restricted to journal papers, peer review, and English, the whole article after title, keyword, and abstract analysis reached to 346. One researcher (Z.S.) imported data from 346 journal articles into Excel CSV files in preparation for a more in-depth investigation. Using Excel's duplication tools, duplicates were discovered and eliminated (Ahsan & Siddique, 2021a). Two independent reviewers evaluated the titles and abstracts of 346 articles (M.A. and Z.S.). To eliminate bias and disputes about article selection were settled by discussion and agreement. Based on the inclusion-exclusion criteria indicated in Fig. 1, a total of 47 papers were identified for qualitative synthesis. For further clarification of the article selection procedure a detail with inclusion and exclusion criteria is presented in Table 1.

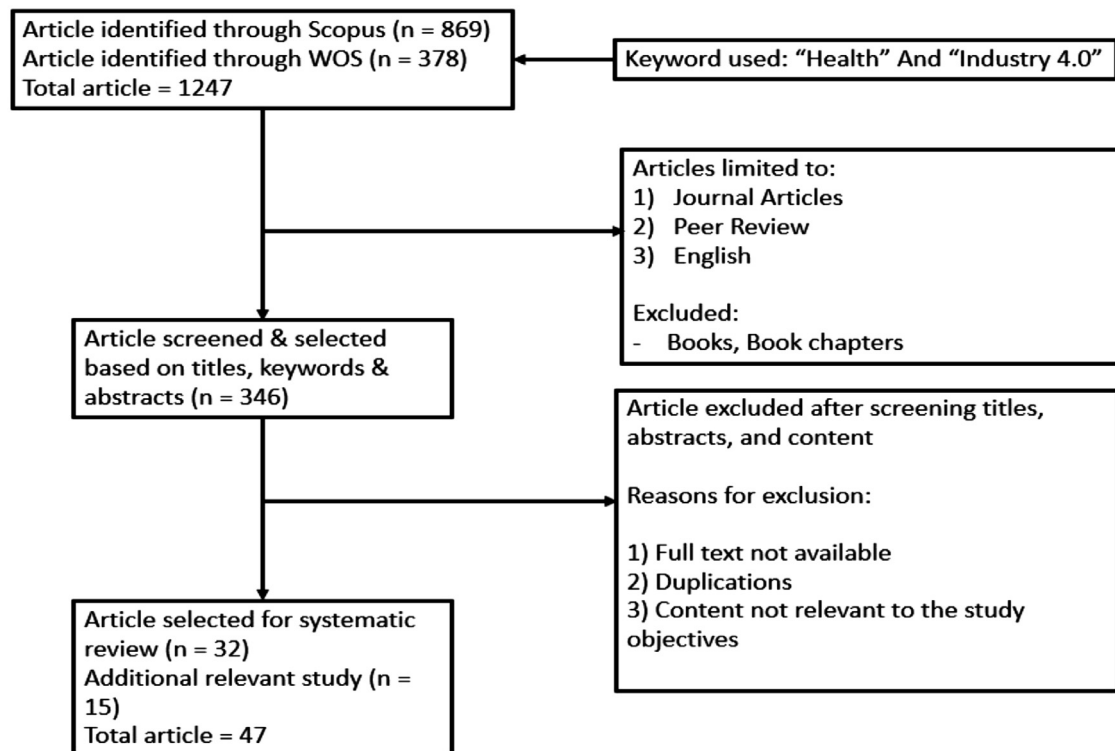


Fig. 1. Flow diagram of article selection procedure used in this study using PRISMA 2015 (Moher et al., 2015).

Table 1
Inclusion and exclusion procedure of referenced literature.

Screening type	Criteria	Inclusion	Exclusion
Title screening	Does the title contain keywords such as industry, industry 4.0 or health care?	346	901
Abstract screening	Does the abstract primarily focused on Industry 4.0 in healthcare?	170	176
Full text screening	Does the article accessible for full text analysis?	32	138
Additional screening	Does the article relevant to this study?	15	-
Total article for final review		47	

3. Findings

Our comprehensive bibliometric analysis and qualitative synthesis fall into three categories: journal statistics, theme-based assessment, and Industry 4.0 in healthcare (IHC) insights. In journal stats, we studied journal statistics by publication year, discipline, journals, citations, authors, and nations. In theme-based assessment, we assessed the title, author keywords, document coupling, thematic evaluation, and historiographic mapping. The study's subsequent sections interpret the major components of IHC based on referenced literature.

3.1. Journal statistics

The following section describes the bibliometric analysis of selected 346 articles. The bibliometric analysis was carried out using Excel data analysis, R-Studio software, and VoSviewer software.

Fig. 2 depicts the large increase in research article publications over the previous seven years, demonstrating a higher degree of interest in the academic community in Industry 4.0 in healthcare (IHC). The statistic shows that the published literature was nearly non-existent between 2005 to 2015. The number of published publications in 2021 is expected to be over 90, while in 2015 it was only 2. We anticipate that the exponential rise in IHC publication will continue in 2022 and later years.

Fig. 3 depicts the IHC literature in a range of subject areas. IHC research is dominated by engineering and computer science, which account for 24.5 percent and 19.8 percent of total publications, respectively. Furthermore, interest in IHC has increased in other disciplines such as material science, mathematics, and so on.

We examined the most productive articles in the IHC domains. Fig. 4 illustrates the top ten journals and the overall number of articles published during the preceding decades. According to referenced literature, the three most productive journals are IEEE Access (21 publications), Sensors (14 articles), and Sustainability (12 papers). Surprisingly, just 13.5 percent of all cited content was published in the top three publications.

The study evaluates the overall number of citations while collecting data and thoughts on IHC's renowned authors. Table 2 displays the ten most frequently referenced publications according to the Scopus and WOS databases. Table 2 shows that each of the authors obtained citations between 44 and 184. Because various databases utilize different indexing techniques and time periods, the total number of citations may differ from Google Scholar and other database citations. According to the Table, the paper published by Del et al. (2019) obtained the most citations (184), with 46 citations each year, followed by the article published by Mittal et al. (2019), which earned 154 citations in total (38.5 citations per year). All of the articles in Table 2 are likely to be among the most prominent articles in the IHC. Table 3 lists the top ten authors who have published the most publications on IHC during the last few decades. Kumar Satish, in comparison to the other authors, published the most papers (4). Authors Khan, Li, Park, and Zalud placed second having three papers.

Table 4 summarizes the top ten most productive countries. We discovered that Italy, the United Kingdom, and China are the most influential nations in scientific production when examining the leading countries. According to Table 4, Italy has 57 published papers, followed by the United Kingdom (35), China (31) and so on.

According to our investigation of the top ten academic institutions, the Technical University of Kosice (Slovakia) is the most productive, with 12 (approximately 3.46 percent) papers published, as shown in Fig. 5, followed by Brno University of Technology (Czechia) with 7 (2.02 percent) published articles.

3.2. Theme-based assessment

The most commonly used terms by researchers in the keywords section were also analyzed because they typically express the study's core topics. R-studio software was used to conduct the analysis.

The equivalent analysis and clustering dendrogram for keywords is shown in Fig. 6. In this case, the height indicates the space between the words and the space indicates how each concept differs from the others.

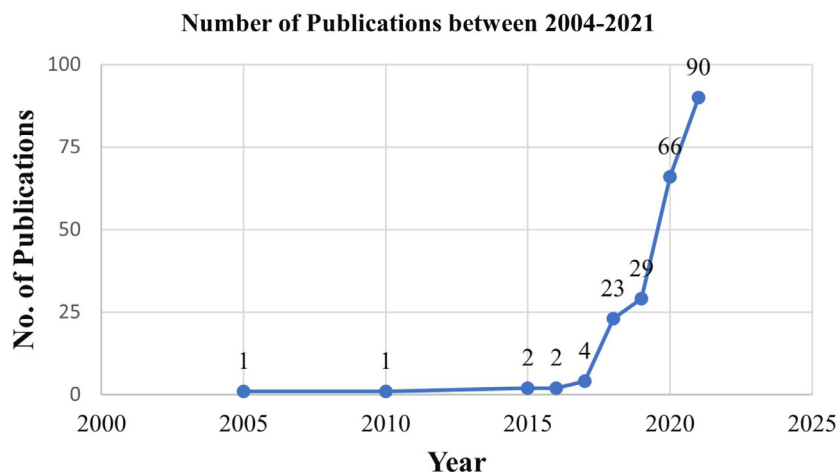


Fig. 2. Publications by year.

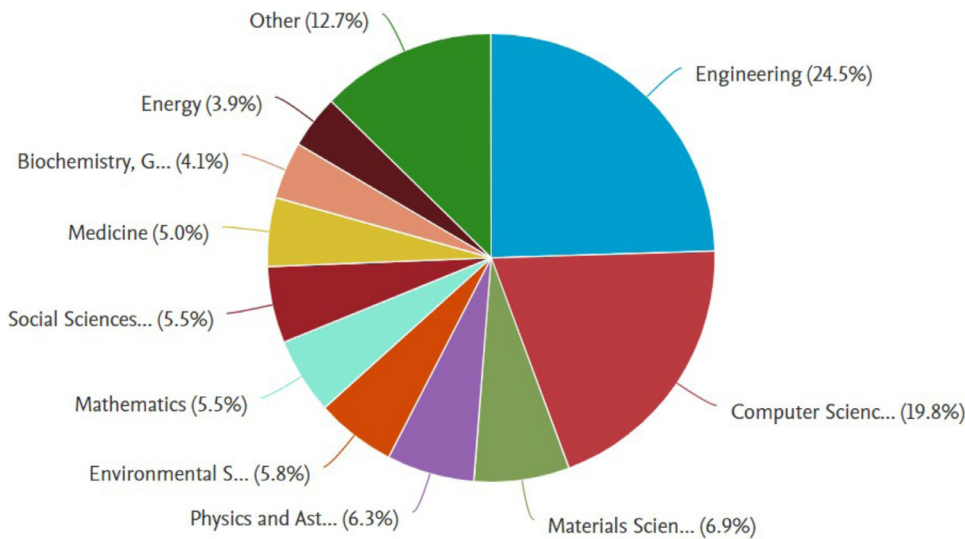


Fig. 3. Documents by subject area.

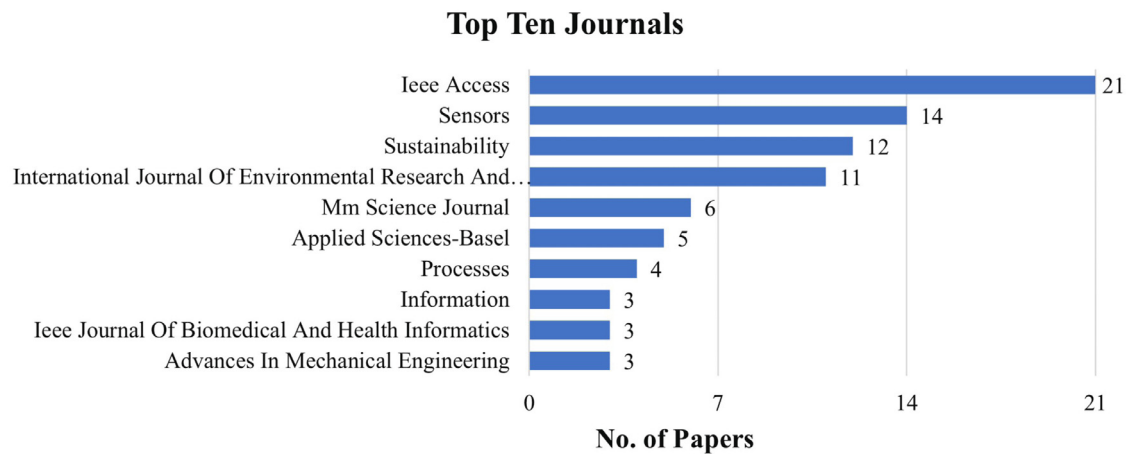


Fig. 4. Publications by Journals.

For the co-authorship of countries analysis, the minimum number of publications for a nation was set to 5, demonstrating the collaboration of authors from diverse geographical locations. As a result, 19 of the 63 countries satisfied the requirement.

Table 5 contains a list of all 19 nations, as well as their relationship strength, number of documents, and total citations.

Scientific collaboration is seen as a critical component in improving the quality and impact of research (Özbağ, Esen, & Esen, 2019). Expanding international collaboration may be accomplished through a variety of methods, including increasing the number of visiting researchers, forming diverse collaborations, and investing substantial funds in research. To enhance international ties, a comprehensive and adaptable research policy is required (Khudzari et al., 2018).

For the research of author co-authorship, a network of co-authors is discovered, and authors who collaborated are identified. Co-authorship analysis (K. Chen, Zhang, & Fu, 2019) is the most often used method for analyzing research collaboration (RC) (Callon, Courtial, Turner, & Bauin, 1983). Researchers' total co-authorship ties are shown in the links. A researcher's co-authorship connection with other researchers (Van Eck & Waltman, 2020) is shown using total link strengths (TLS). The minimum number of documents and citations for one author was set to two and ten, respectively, for the purposes of author co-authorship analysis. Only 49 out of the 773 authors met the criteria. As a result of the close connections among the 49 authors, different distinct groups emerged. This group of six authors has a wide range of expertise and a

long history of working together. Table 6 displays the links, TLS, documents, and citations for top ten authors. Lee J. has four published articles and 2478 citations and has the highest total link strength (TLS=7), followed by Gosine R. (TLS=6, documents=2, and citations=19), and James L. (TLS=6, documents=2, and citations=19).

The author's keyword sections convey information in a unique way. "Co-occurrence" refers to the frequency with which words appear in specific publications (Callon et al., 1983; N. Khan & Qureshi, 2020). The total length of a word's strength indicates the number of times it appears in a document. The node size represents the frequency of the words, for example, the larger the node size, the more common the phrase. A thicker line connecting two or more words shows that they are close to a cluster. Scopus data were imported into the VOSviewer application for author keyword co-occurrence analysis. With a minimum of five keyword occurrences, 385 of 4230 keywords were found. Each of the 385 keywords was classified into one of five clusters. Vosviewer's co-occurrence networks are depicted in Fig. 7. For instance, Keywords in cluster 1 include big data, deep learning, machine learning, prognostics, and health management.

The R-Studio application was used to conduct the bibliographical coupling analysis. The linking of studies that reference each other is an essential aspect of bibliographic coupling. Our unit of analysis had been determined, and our counting technique had been meticulously followed. The minimum number of units for this study is 25, the minimum clustering frequency is 5, and the number of labels per cluster is 5.

Table 2
Top 10 cited papers published in IHC.

Author(s)	Article Titles	Citation	Citation/Year
Del Ser et al. (2019)	Bio-inspired computation: Where we stand and what's next	184	46
Mittal, Khan, Romero, & Wuest (2019)	Smart manufacturing: Characteristics, technologies and enabling factors	154	38.50
Pace et al. (2018)	An edge-based architecture to support efficient applications for healthcare Industry 4.0	149	37.25
Javaid et al. (2020)	Industry 4.0 technologies and their applications in fighting COVID-19 pandemic	137	45.67
Reis & Gins (2017)	Industrial process monitoring in the Big Data/Industry 4.0 Era: from detection, to diagnosis, to prognosis	104	17.33
Grapov, Fahrman, Wanichthanarak, & Khoomrung (2018)	Rise of deep learning for genomic, proteomic, and metabolomic data integration in precision medicine	83	16.6
Gupta et al. (2020)	Smart contract privacy protection using AI in cyber-physical systems: tools, techniques and challenges	50	16.67
Abdel-Basset, Chang, & Nabeeh (2021)	An intelligent framework using disruptive technologies for COVID-19 analysis	50	25
Khalid et al. (2018)	Security framework for industrial collaborative robotic cyber-physical systems	46	9.20
Pilloni (2018)	How data will transform industrial processes: crowdsensing, crowdsourcing and big data as pillars of industry 4.0	44	8.8

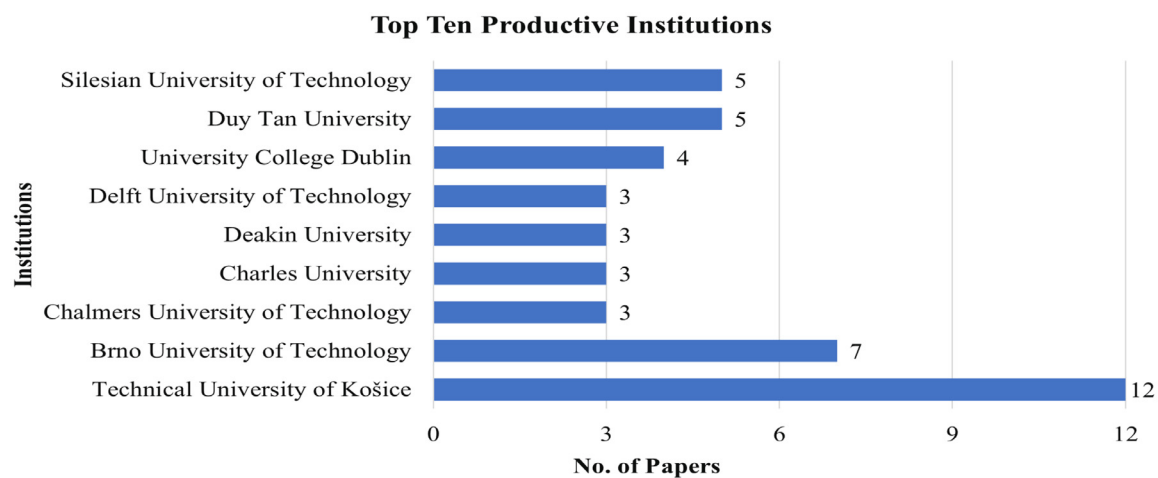


Fig. 5. Top ten institutions based on number of publications.

Table 3
Most influential author in terms of total publications.

Authors	No. of Articles	Articles Fractionalized
Kumar S	4	0.92
Khan M	3	0.67
Li Y	3	0.58
Park H	3	0.92
Zalud L	3	0.88
Ahmad M	2	0.46
Ajayi O	2	0.67
Algarni F	2	0.42
Andonegui I	2	0.50
Bagula A	2	0.67

Table 4
Top ten most productive countries.

Country	Articles
Italy	57
UK	35
China	31
India	29
Spain	29
USA	28
Germany	24
Brazil	23
Czech Republic	19
Australia	14

Table 5
Analyses of countries' Co-authorship.

Country	Documents	Citations	Total Link Strength
United States	26	2855	20
India	23	875	18
China	24	290	17
Australia	12	88	17
Pakistan	12	217	17
United Kingdom	18	591	13
Saudi Arabia	7	281	12
Italy	31	469	9
Germany	18	249	9
Brazil	14	132	9
Spain	14	318	7
Malaysia	6	6	6
Portugal	6	187	5
Canada	9	177	4
South Korea	7	176	4
France	6	102	4
Poland	6	33	3
Taiwan	6	49	2
Indonesia	5	65	2

The wider the circle in Fig. 8, the stronger the bibliographic connection appears to be. The most prominent cluster was discovered in articles addressing keywords such as future internet, clean manufacturing, and sensor, with a total frequency of 11 and a centrality of 3.91.

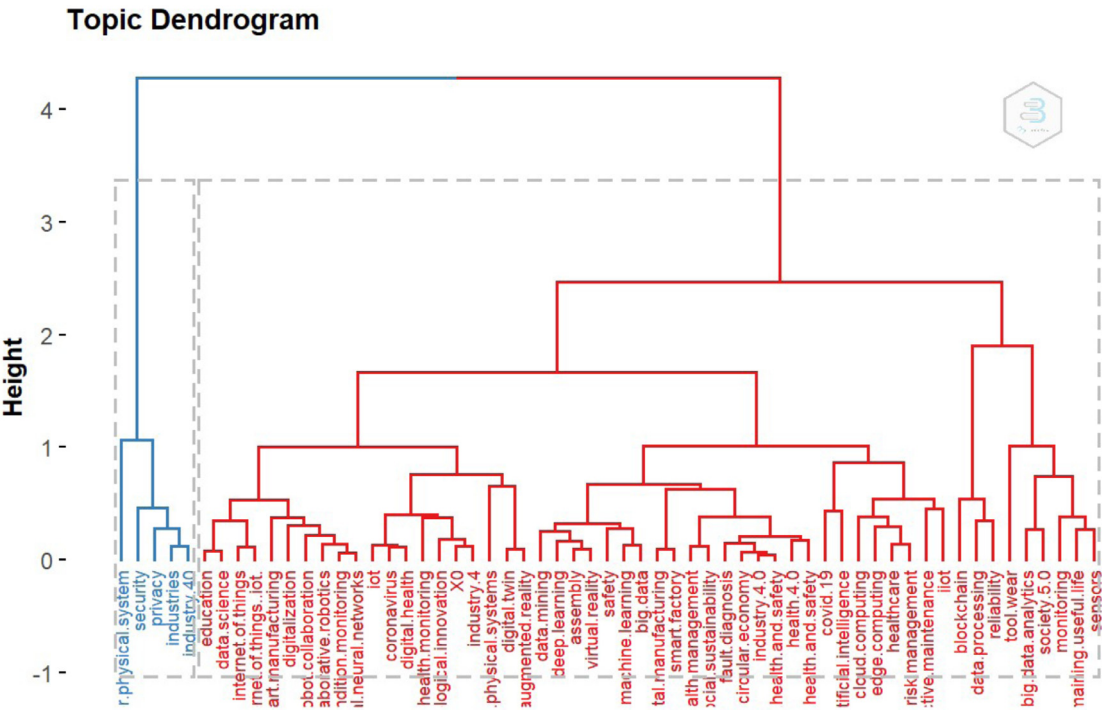


Fig. 6. Dendrogram of authors keywords.

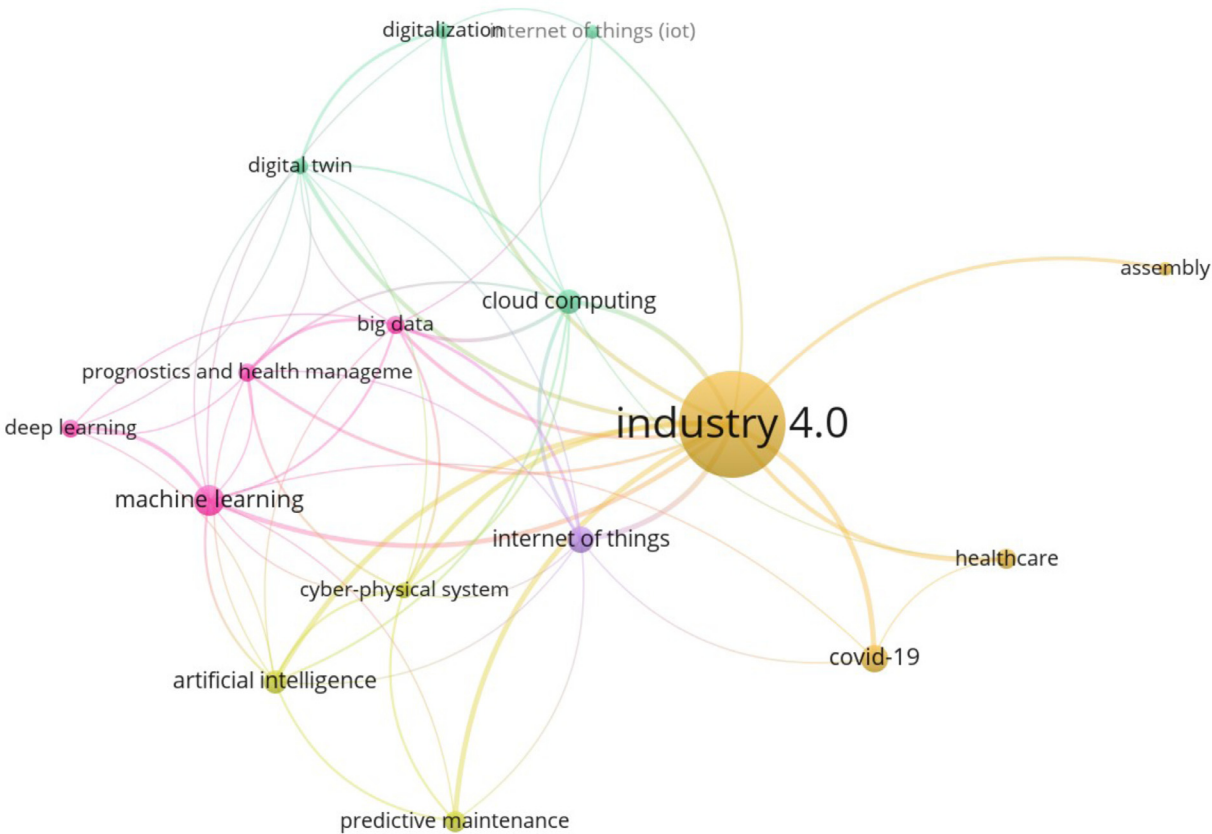


Fig. 7. Co-occurrence of author keywords networks developed by VOSviewer.

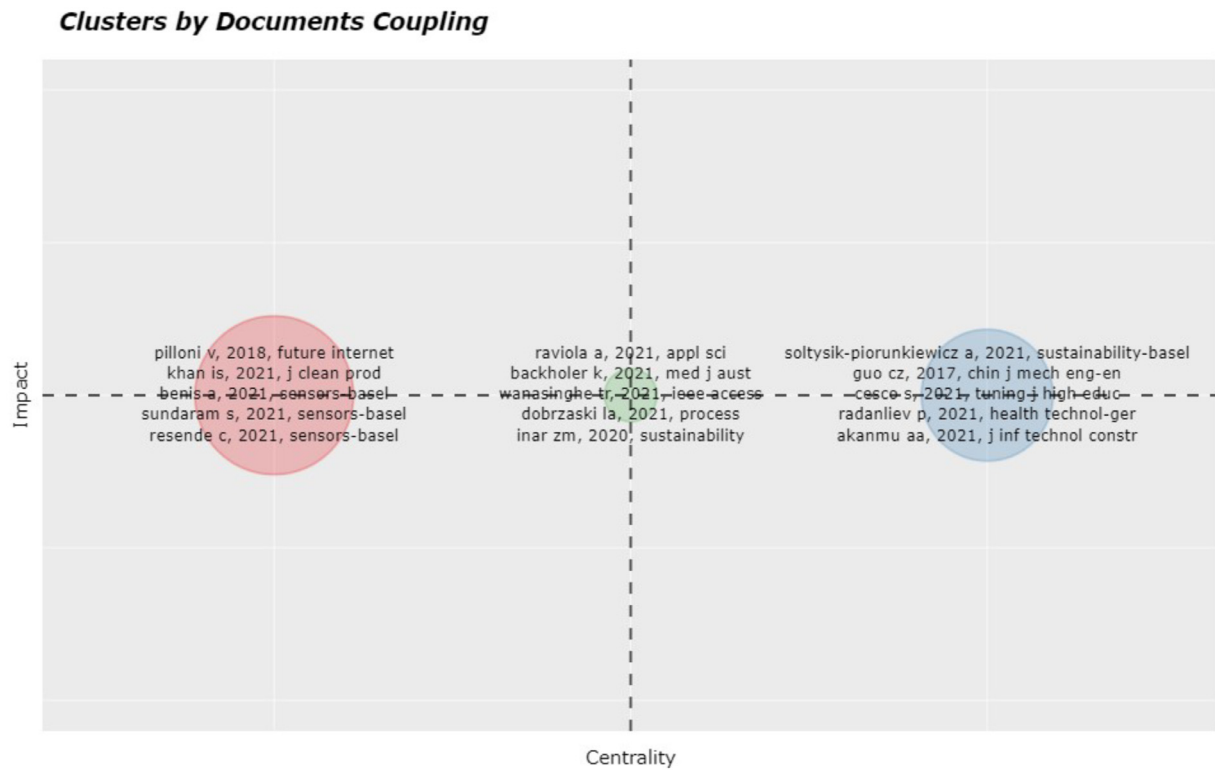


Fig. 8. The bibliometric map representing documents coupling.

Table 6
Co-authorship analysis of authors.

Author	Documents	Citations	Total link strength
Lee j.	4	2478	7
Gosine R.	2	19	6
James L.	2	19	6
Wanasinghe T.	2	19	6
Warrian P.	2	19	6
Azamfar M.	2	91	5
Singh J.	2	91	5
Dobrzańska A.	2	13	4
Dobrzański L.	2	13	4
Dobrzański B.	2	13	4

In Fig. 9, based on the distribution of publications each year, we divided our collection into three time periods: 2005–2018, 2019–2019, and 2020–2022. Fig. 9 illustrates a thematic assessment of the authors' concept based on title analysis. Topics such as industry, system, and industrial began as specialized themes, and by 2019–2019, a different topic such as technology, healthcare, care, and the framework merge with those topics. Manufacturing, smart, and production become significant ideas in IHC between 2020 and 2022, as seen in Fig. 9.

Fig. 10 depicts a historiographic mapping based on the document titles. Each node in the graph indicates a document from the examined dataset that has been mentioned by another document. In addition, each title is represented by a distinct edge. For example, Chute & French (2019) published a paper in 2019 that was cited in one publication in 2020 and three articles in 2021.

4. Insights of IHC

In this section, Industry 4.0 and healthcare (IHC) have been analyzed in detail based on the selected 47 articles. The following section presents the papers' classification according to seven major categories in IHC.

The literature has been classified as (i) conceptual framework healthcare 4.0, (ii) schedule problems, (iii) security issues, (iv) COVID-19, (v) digital supply chain, (vi) blockchain technology, and (vii) artificial intelligence. We developed a framework that integrates the six major key components that are related to IHC based on the referenced literature. Fig. 11 illustrates the proposed IHC framework based on relevant literature.

4.1. healthcare 4.0

Healthcare has been around since the beginning of civilization, but in the last few decades, it has evolved dramatically. Healthcare 1.0 was largely limited to providing physical health services, such as checking vital signs and delivering babies via natural means. Then, with the advent of modern medicine, healthcare 2.0 added mechanical services like surgery and medical machines to its repertoire. Healthcare 3.0 patient-centric, and healthcare 4.0 deals with cloud computing, fog computing, and IoT. With growing population and technological facilities, it is becoming pertinent to facilitate the healthcare service with better facility and flexible manner. According to Jayaraman et al. (2019) healthcare 4.0, is a relatively new phrase developed from Industry 4.0 (Jayaraman, Forkan, Morshed, Haghighi, & Kang, 2020). In healthcare 4.0, data-driven digital health technologies include innovative health, online health, mHealth, mobile health, wifi health, eHealth, telehealth/telemedicine, medical information technology, digital medicine, health informatics, ubiquitous health, and health information systems (Jayaraman et al., 2020).

The emerging of COVID-19 demonstrated why it is critical to consider IHC when developing various approaches that may serve both patients and practitioners while providing security, accountability, and system efficiency—digital technology aids in the establishment of a safe working environment for healthcare professionals (Kaiser et al., 2021).

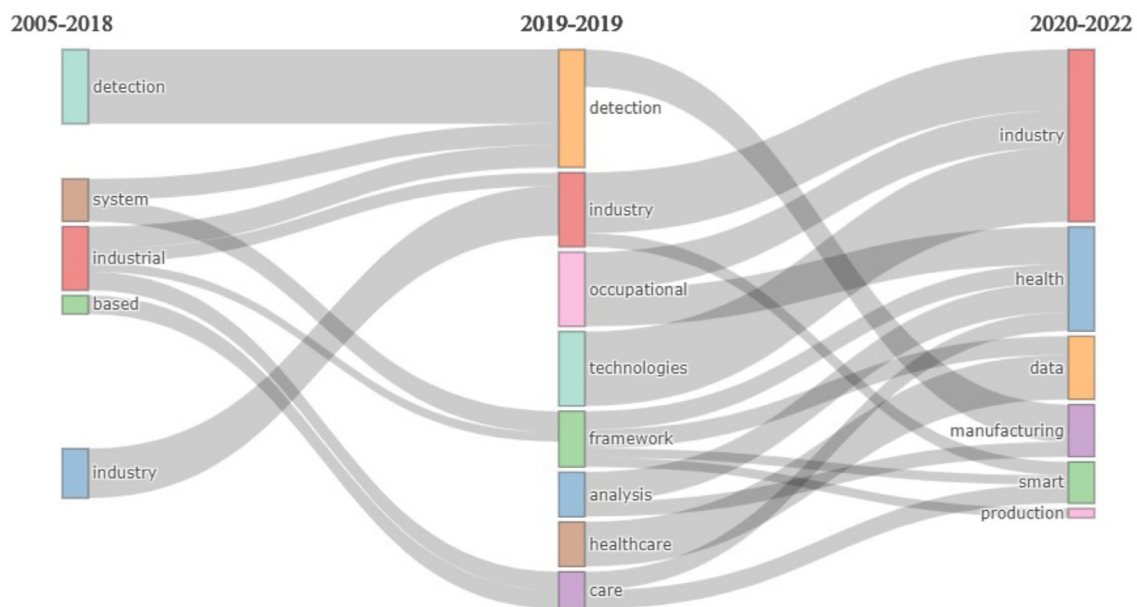


Fig. 9. Thematic assessment of the authors' notion based on title analysis.

Historical Direct Citation Network



Fig. 10. Historiographic mapping.

A few studies that have been mentioned a conceptual framework for more effective and efficient health-care systems. For example, [Dobi et al. \(2019\)](#) provide a novel technique that is appropriate for use in the health care business, specifically for monitoring a patient’s health features. The framework is built using Markov chain-based techniques. The Markov chain’s stationary distribution may be used to estimate the average cost of the procedure, which is determined by the time between samplings and the control limit ([Dobi & Zempléni, 2019](#)).

Benis et al. (2021) presented one digital health, a cohesive framework for long term health environments. The conceptual framework

for one digital health is based on two core concepts (one health and digital health), three perspectives (individual health and well-being, people and community, and environment), and independent variables (citizen engagement, education, environment, human and veterinary healthcare, and healthcare, Industry 4.0). One digital health's goal is to digitalize long-term health settings through the adoption of a systematic life and health sciences approach that considers multiple digital technology views on public health, animal health, and environmental management. Other issues, such as the exchange of electronic health information, are, however, unresolved within the

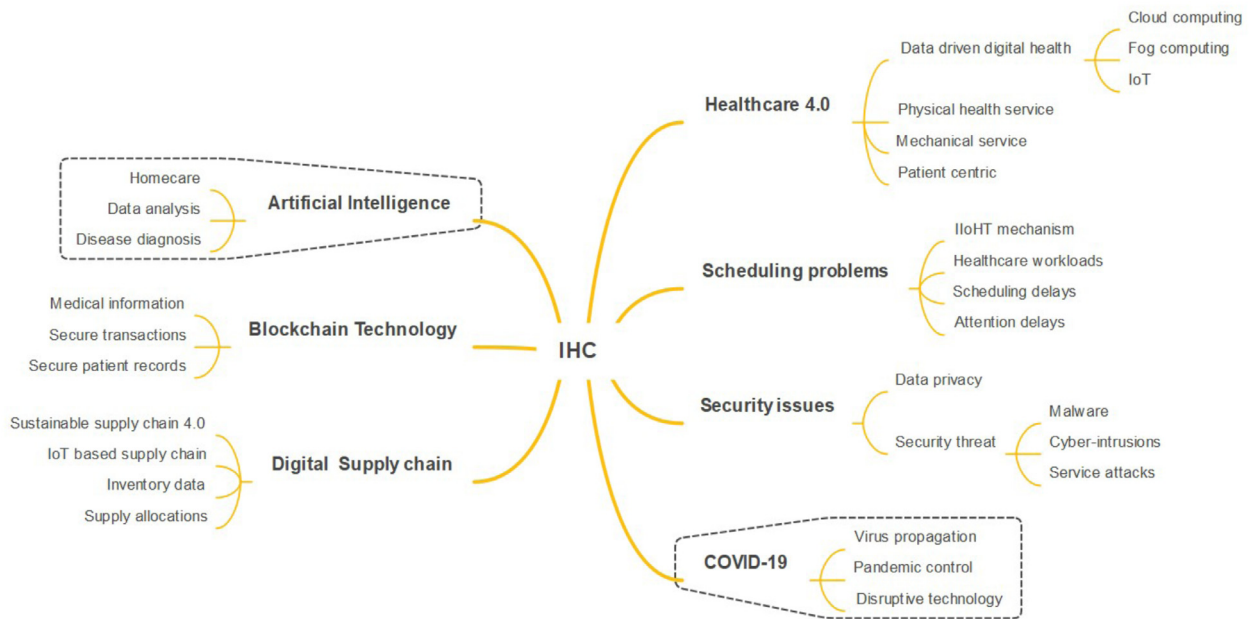


Fig. 11. Framework of IHC based on referenced literature.

jurisdiction of primary healthcare systems (Larrucea, Moffie, Asaf, & Santamaria, 2020).

4.2. Scheduling problems

Scheduling problems entail determining the ideal schedule given various objectives, system conditions, and job characteristics. While manufacturing plant, garments industry extensively faces scheduling problems, during the last decades, healthcare systems have also considered scheduling problems one of the key factors that cause the bottleneck of the smart healthcare systems. Several studies identified schedule problems in healthcare sectors and proposed a new scheme to solve those challenges. Dootio et al. (2022) developed the lightweight remote procedure call (RPC) for the IloHT mechanism. The study dealt with schedule problems and scheduled all healthcare workloads under their deadlines. The study uses linear integer programming that helps to reduce the scheduling delay up to 50% compared to the existing RPC (Dootio et al., 2021).

Chauhan et al. (2021) established and studied seven principles linked to smart healthcare waste disposal systems with circular economy characteristics to retrieve value of disposables using a decision-making trial and evaluation laboratory (DEMATEL) technique. A causal diagram was used to select the criteria based on their relevance and net cause and effect connection (Chauhan, Jakhar, & Chauhan, 2021).

Most of the smart health services are hospital oriented. Additionally, patients' data are not organized and application dependent, causing attention delays in many cases. To overcome such scenarios, Bedon et al. (2020) developed a home-based smart health model considering the internet of things (IoT), internet of medical things, and smart health applications. The proposed health service reduced the attention delays compared to existing healthcare facilities (Bedón-Molina, Lopez, & Derpich, 2020).

Ajayi et al. (2019) aim to solve the scheduling problem in Africa by developing interconnected medical facilities across the nations. A cooperative and competitive collaboration model was developed considering two allocation schemes such as Genetic Algorithm-based VM Allocation (GAVA) and Stable Roommate Allocation (SRA) (Ajayi, Bagula, & Maluleke, 2020). However, one of the limitations of that study is that the study result was based on the simulation model. Therefore, the

question was raised regarding the performance of the proposed model in real-world scenarios.

4.3. Security issues

Patient data privacy is one of the most urgent issues in the healthcare sector. According to a 2020 study published in cybercrime magazine, 93 percent of U.S. healthcare organizations have experienced a severe security breach that resulted in data breaches, denial-of-service attacks, malware, or other cyber-intrusions. It is impossible to determine how frequently individuals' EHR (electronic health record) systems have been hacked without doing an audit of their EHR (electronic health record) system (Morgan, 2022). Cloud settings have become one of the most enticing areas for hackers since the bulk of healthcare systems store patient data on the cloud. In view of the security difficulties in IHC, multiple studies suggested several protective techniques to secure cloud-based medical data.

As a result, the healthcare business is working to develop a cloud server that requires a higher level of security and authenticity. Signcryption, a mix of signature and encryption, for example, has demonstrated promising outcomes in cloud-based access systems. The bulk of them, however, are better suited to homogeneous rather than heterogeneous situations. Ullah et al. (2022) developed an access control mechanism for IoT settings that leverages heterogeneous signcryption to overcome these issues. According to the authors, their proposed technique might survive a range of risks such as secrecy, integrity, and so on (Ullah, Zahid, Algarni, & Khan, 2022). Khan et al. (2022) carried out similar research. Furthermore, the author created an efficient signcryption technique for IoT. The IoT makes use of the internet as a key channel of communication for single documents as well as multi-digital communications. The authors investigated the following security characteristics in terms of processing cost and transmission bandwidth: anonymity, untraceability, confidentiality, and unforgeability. The authors developed a lightweight and secure proxy blind signcryption for multi-digital communications using a hyperelliptic curve (HEC), which is computationally less costly and provides higher transmission capacity (Khan et al., 2022).

Care 4.0, an integrated care paradigm presented by Chute et al. (2019), aims to provide patients the maximum control

over their medical information. Care 4.0's overarching objective is to build trustworthy and connected networks that are linked with digital health and care services. The planned care 4.0 networks and technology may assist individuals in managing and utilizing their assets, both inside their local care circle and throughout the larger community (Chute & French, 2019). In addition to Chute et al., Pace et al. (2019) proposed an efficient application for healthcare industry 4.0. A simple client module that supports multi-radio and multi-technology is constructed to collect local data. One of the potential advantages of their proposed architecture is that the capabilities are accessible via both private and public cloud platforms, providing for better flexibility and resilience. In real-time testing, the proposed design beat competing devices in terms of data transmission and processing time (Pace et al., 2018).

Rather than that, Alvarado et al. (2020) defines healthcare 4.0 as the adoption of three key paradigms: the internet of things, big data, and cloud computing, all of which are changing eHealth and its whole ecosystem in the same manner as Industry 4.0 is modernizing manufacturing (Borregan-Alvarado, Alvarez-Meaza, Cilleruelo-Carrasco, & Garechana-Anacabe, 2020).

4.4. COVID-19

Over 800 million people have been left without basic healthcare as a result of the present COVID-19 crisis, which has resulted in a worldwide epidemic of life-threatening illnesses. While the death toll is believed to exceed 55,000,00, with an additional 2 million hospitalized each week, this problem is not going away any time soon (Dashbord, 2020; Ahsan, Gupta, et al., 2020; Ahsan et al., 2021; Ahsan, EAlam, et al., 2020; Ahsan et al., 2022). Mobile applications, robots, Wi-Fi cameras, scanners, and drones are being utilized to combat virus propagation. Industry 4.0 has had an impact on the important contribution of digital technology to pandemic control (Narayanamurthy & Tortorella, 2021).

The world was in the grip of an unprecedented healthcare crisis at the height of COVID-19. As a result, academics and practitioners develop a wide range of tools and techniques to digitalize the systems to minimize disease transmission and increase the number of healthcare facilities. For example, Majeed & Lee (2021) developed a person-specific data collection strategy to decrease COVID-19 dissemination. One of their research's potential contributions is to use high computing technologies to provide people with COVID-19-related knowledge in order to promote awareness. The recommended technique takes security into account when constructing prototype systems for users (Majeed & Lee, 2021).

Abdel et al. (2021) created an intelligent framework for COVID-19 analysis using disruptive technologies. The suggested approach, according to the authors, will help in the prevention of COVID-19 outbreaks, preserve the safety of healthcare staff, and protect patients' physical and psychological well-being. In response to the medical team's lack of personal protective equipment (PPE), the framework was created (Abdel-Basset et al., 2021).

According to Pérez Sust et al. (2020), disruptive technologies lessen the load on health personnel during the COVID-19 epidemic (Pérez Sust et al., 2020). Individuals infected with COVID-19 can be monitored utilizing cutting-edge monitoring technologies. In the instance of COVID-19, public health advocates argue that disruptive technology is essential for public health (Benjamin, 2020).

However, as the world is struggling to deal with COVID-19, it is assumed that the existing IHC systems are not enough to handle the situation. As of January 2022, the current COVID-19 infected cases are 307,685,974 (Dashbord, June, 2020), ultimately developing an extended crisis in healthcare. Thus, researchers and scholars should develop new solutions that might be more impactful in the current scenario in the healthcare sector.

4.5. Artificial intelligence

AI or artificial intelligence has got a warm welcome into the medical and healthcare industry (Abdel-Basset et al., 2021). AI is growing exponentially in the world of medicine and is currently seen as one of its most essential forms (Paul et al., 2021; Ahsan, E Alam, et al., 2020). With many healthcare facilities already using such equipment, one can now see how it plays an important role in industrial 4.0 and healthcare. Today, several virtual reality-based systems are being employed to help doctors in disease diagnosis, while some other equipment uses sophisticated systems that work with the data obtained from patient records while keeping them secure at all times (N. Khan & Qureshi, 2020). Machines that can recognize handwriting have also been put to extensive use by hospitals, where they are used for writing prescriptions for patients after analyzing their medical records (Sadman et al., 2020).

AI dominated IHC and was introduced by many referenced literatures. For instance, Yang et al. (2020) proposed homecare robotic systems using cyber-physical systems (CPS) (Yang et al., 2020). Mohanta et al. (2019) predicted a paradigm shift in digital healthcare systems using AI, IoT, and 5G communications. AI integrated with wearable devices with sensors might help to monitor, collect, and diagnose disease based on the data analysis without human intervention. The authors introduced this advanced development in the health sector as healthcare 5.0 (Mohanta, Das, & Patnaik, 2019).

The AI technology has already begun entering medicine in an attempt to single out symptoms of illnesses that doctors may not notice. The advent of this technology will allow for better monitoring of patient conditions, allowing for more personalized care plans based on individual needs (Szolovits, 2019). As an example, one can take the case of 'predictive' software that is being used by many hospitals today. This particular form of AI helps in detecting heart attacks even before they occur by way of analyzing the patient's ECG signals and other vital signs (Ahsan, Mahmud, et al., 2021). It then provides a warning to doctors about the increased likelihood of an impending heart attack so as to help them intervene beforehand. Such kinds of equipment are pretty expensive but are being extensively used for better results. Such high-end systems have helped doctors in saving countless lives worldwide.

An AI system can also be used with brain scans of patients suffering from Alzheimer's disease, dementia, or stroke victims who may not remember their names or how they look anymore. Doctors are also increasingly using AI systems for performing medical operations like tumor removal, knee replacement surgeries, etc., while surgeons often use virtual reality equipment for their training exercises (Najarian, Fallah-nezhad, & Afshari, 2011). Medical students can also make use of such equipment to better understand how the human body works during the course of an operation. Using intelligent software technology in combination with GPS devices placed on vehicles, ambulances can now get real-time information about the quickest routes to emergency situations, while some hospitals even employ robots that work 24/7 by feeding patient data into their system while overseeing their medication requirements (Nanwani, Kshirsagar, Kawalkar, & Deshmukh, 2017).

4.6. Blockchain technology

Blockchain has various applications in healthcare. For example, blockchain technology, has the potential to merge patients' medical information and prescription data from several locations into a single set of updated records (Zhang, Schmidt, White, & Lenz, 2018; Engelhardt, 2017). For instance, Rupa et al. (2021) developed an Industry 5.0-based blockchain application to keep medical credentials on the remix ethereum blockchain (Rupa, Midhunchakkaravarthy, Hasan, Al-humyani, & Saeed, 2021). Liu et al. (2017) suggested a new blockchain-based approach for a dependable and efficient medical record exchange system. One of the possible benefits of the suggested model is that it is a cost-effective technique that allows the user to immediately access the information without compromising security. However, one potential

disadvantage is that the research does not address how existing e-health records would be integrated with the proposed architecture (Liu, Zhu, Mundie, & Krieger, 2017).

Christo et al. (2019) advocated blockchain technology as a distributed solution to provide security while accessing medical reports. The proposed scheme includes authentication, encryption, and data retrieval. The authors claimed that the proposed framework protects the patients' records compared to other existing techniques (Christo, Sarathy, Priyanka, & Raj, 2019).

Kumar et al. (2020) demonstrated a wearable kidney system based on healthcare 4.0 protocols and utilizing blockchain technology. The author used game theory to design resource-constrained renal systems. The proposed system, according to the authors, would be an example of the shift away from specialist or departmental-centric methods and toward data and patient-centric approaches, bringing more transparency, trust, and good practices to the healthcare business (A. Kumar, Kumar Sharma, Nayyar, Singh, & Yoon, 2020).

4.7. Digital supply chain

The digital supply chain enables the timely and cost-effective delivery of the right product to the right patient (AlMudimigh, Zairi, & Ahmed, 2004). The digital supply chain adds another layer to healthcare systems by lowering costs, reducing needless deviations, and increasing patient care and involvement. Dau et al. (2019), for example, offer a circular economy transition paradigm to investigate the healthcare sustainable supply chain 4.0. The proposed paradigm for healthcare systems emphasized social responsibility (Daú, Scavarda, Scavarda, & Portugal, 2019).

During the SARS-COV-2 outbreak, Zahedi et al. (2021) established an IoT-based supply chain network. The proposed approaches shorten the response time of the ambulance. In addition, the proposed model minimizes the overall crucial reaction time. In Iran, the proposed supply chain model was tested in real-world scenarios. Over three weeks, the experimental findings show that the recommended methods reduced the COVID-19 case by up to 35.54 percent (Zahedi, Salehi-Amiri, Smith, & Hajiaghahi-Keshteli, 2021).

Fathollahi-fard et al. (2019) develop a bi-objective location-allocation-routing model for a Green Home Health Care Supply Chain (GHHSC). The authors introduced five newly adopted annealing techniques using simulation approaches. Their final result demonstrates satisfactory results regarding the total cost of the system and environmental pollution. However, as the proposed approach may not function as expected in recent times due to the ongoing crisis of COVID-19 yet required to modify the proposed scheme considering additional barriers (i.e., lockdown, transportation delay, route schedule) (Fathollahi-fard, Govindan, Hajiaghahi-Keshteli, & Ahmadi, 2019).

In addition, supply chain-related issues such as inaccurate inventory data, delayed supply allocations, slow repurposing of manufacturing facilities, and lack of innovations are ongoing challenges that need to be addressed in healthcare systems to develop dynamics IHC (Sidhu, 2015; Wickramasinghe, Al-Hakim, Gonzalez, & Tan, 2014).

5. Discussions

We began our study with a bibliometric analysis to provide the context for Industry 4.0's recent endeavor in healthcare. The study's findings may provide insight into the universe of publications on this subject. Italy, the United Kingdom, and China are the most prominent and emerging nations of publications, author collaborations, and overall contributions, and this trend is expected to continue in the near future.

Finally, in order to conduct an in-depth assessment of IHC, we identified 32 referenced literature (in a systematic way) and an additional 15 relevant publications (in total 47). We developed a conceptual framework with six essential components: scheduling problems, security issues, COVID-19, digital supply chain, blockchain technology, and ar-

tificial intelligence. Our research reveals that each of these six critical factors serves as the constraint/ingredient in the present development of smart healthcare. We uncovered some practical implications of Industry 4.0 in healthcare and some prospective avenues for future study, based on our conceptual framework and analysis.

5.1. Practical implications

The recent digitalization of healthcare introduces a new phase that merged with industry 4.0 and is now recognized as healthcare 4.0. Innovative technologies such as mHealth, wifi health, eHealth are widely adopted in IHC. Several studies considered optimization approaches to reduce one of the pressing issues in healthcare— the scheduling delay (Dootio et al., 2021; Bedón-Molina et al., 2020). IoT is one of the most important merging areas in IHC, allowing people and things to be linked at any time and from any location, allowing them to obtain their desired services. A better example is telemedicine, which is frequently used in IHC to meet the demands of patients as a result of the current epidemic.

Based on the comprehensive investigation, it was discovered that blockchain technology has potential applications in the health industry because of its strong distribution, encryption, immutability, and tokenization pillars (Jain, Dash, Kumar, & Luthra, 2021). As the healthcare business evolves at a rapid pace, blockchain technology enables decentralized solutions that benefit all parties, including patients and providers. Many of these solutions are in their early stages. Nonetheless, they offer a great deal of potential as the industry investigates new areas where blockchain technology might be implemented in various health care sectors.

One of the revolutions in IHC we have observed is due to the increasing activities of m-commerce (Chhonker, Verma, Kar, & Grover, 2018) and its adoption in the healthcare sector. For instance, social awareness about COVID-19 and receiving test reports using online systems are quite a few examples.

The practical implication of AI has been observed in healthcare in terms of diagnosis, data analysis, and storing patient reports automatically. The next decade will be a defining period for the progress of AI in healthcare, which has been brought to attention by large tech companies. In Asia, AI is used as a tool for healthcare providers to receive continuous training and conduct diagnoses (Guo & Li, 2018). In the United Kingdom, AI provides activities such as personalized treatment for kidney transplant patients (Coates et al., 2020). In US hospitals, AI has been implemented in health care during emergency situations due to the increasing demand for medical physicians (El Hechi et al., 2021).

5.2. Future agenda

In only ten years, artificial intelligence in healthcare is predicted to earn more than \$100 billion in revenue and have a market value of more than \$3 trillion (Bornet, Barkin, & Wirtz, 2021). This surge will bring new possibilities for enterprises but also introduce new dangers and problems that must be addressed properly. There are various important ways in which artificial intelligence might help to enhance clinical care and overall patient treatment provision. AI will be employed in patient diagnosis and therapy to offer continuous feedback on an individual's health. On the other side, medical experts are concerned about the safety standards for using AI solutions for clinical requirements. The use of AI in healthcare services might be in a variety of sectors, including remote patient monitoring, individualized treatment for specific patients, and medication development. Therefore, future research should concentrate on enhancing cooperation between human physicians and artificial intelligence in order to maximize the benefits of both parties throughout their partnership.

Despite its numerous benefits, blockchain technology remains a susceptible area in healthcare due to big data availability. As a result, future studies should concentrate on big data, privacy, ransomware attacks, and ensuing the market fraud and spam (Jain et al., 2021). Additionally,

adapting big data analysis on digital platforms utilizing text mining (S. Kumar, Kar, & Ilavarasan, 2021) might bring fresh insights in developing smart service management in IHC. Medical research is one of the most promising blockchain applications in healthcare. The healthcare business requires massive investment to conduct life-changing research for improved treatments and cures for diseases such as cancer, Alzheimer's, and diabetes. Furthermore, some organizations have adequate finances but are unable to carry out the tasks they desire due to the difficulty in locating benefactors with considerable resources.

Many logistic systems, such as port logistics and roadways, have been disrupted as a result of COVID-19. In addition, the inconsistent logistical assistance fails to adhere to the proper supply and demand workflow. As a result, with COVID-19 as a persistent barrier, a new universal logistic method that can supply adequate logistics in the healthcare sector to run the systems successfully must be developed. Still, some of the authors' concerns, such as coordination challenges, terminal congestion, a lack of data-driven decision-making, and insufficient employee incentives, must be addressed in order to establish more robust supply chain systems in IHC (Sarkar & Shankar, 2021).

Even while industrialized nations can give healthcare services through telemedicine, less affluent countries such as Bangladesh, India, Nepal, and numerous refugee regions continue to suffer. As a result, future work should concentrate on a more advanced or flexible method that may result in a chance to serve in underrepresented regions (Chhonker et al., 2018).

In order to move IHC 4.0 forward, it is also important to build digital policy, legislation, and governance, which are now unconsidered. The role of human characteristics in misuse is always a threat in IHC, which must be addressed in the future study (Agarwal, Chauhan, Kar, & Goyal, 2017).

While the majority of the research focused on data-driven techniques, there are still limited resources (e.g., people, time, and equipment) and a vast quantity of work to be done, as well as certain limits on when activities must begin and conclude. Therefore, future research should emphasize on several variants of the problem in IHC. Still, they all boil down to finding a schedule that minimizes cost, maximizes profit, or makes other objectives as feasible as possible. It is high time to consider the geographical locations, resource allocations, and social circumstances (e.g., COVID-19), as potential barriers and constraints in developing smart scheduling in healthcare, which might draw attention to future researchers.

Because the majority of patient information transactions are now conducted via a cloud service, cloud servers have become a target for hostile assaults. In order to provide a secure facility for patients' online access, many research suggests heterogeneous signcryption or secure proxy servers. However, as IHC advances, so does the number of fraudulent transactions and identity theft. As a result, future research should integrate the IoT with a strong risk management plan, which will aid in the identification of problems and the establishment of control mechanisms to reduce or eliminate hazards; this includes collecting information on threats before performing an assessment of vulnerabilities and impact. Not only for the patients but also to offer security throughout healthcare delivery, it is vital to identify strategies to protect the interests of personnel, visitors, and clients.

6. Conclusions and remarks

Healthcare professionals have traditionally relied on technology to assist them give the best care to their patients, but significant advances in the previous decade have improved treatment quality and patient outcomes. Healthcare is always changing, but one constant remains: the necessity for a secure healthcare system free of data breaches. Today, health data may be found in electronic medical records (EMR), personal health records/digital health records, clinical data repositories (CDR), and health information exchanges (HIE). These archives hold essential information that must be protected, yet hackers routinely target it. Be-

cause hackers are starting to target hospitals, healthcare organizations are finding that ensuring their IT infrastructure is intact and working is no longer enough. The fourth industrial revolution (IR) is the next generation of intelligent healthcare technologies that enable physicians and other professionals to more effectively manage disease transmission, protect their patients from dangerous illnesses, and receive real-time assistance when they are most needed. This study included a bibliometric examination of 346 publications on Industry 4.0 and healthcare (IHC). According to the conclusions of the survey, Italy is the most prominent country in terms of using Industry 4.0 in healthcare, followed by the United Kingdom and China. The three most productive journals in IHC in terms of total number of articles are IEEE Access, Sensors, and Sustainability. Kumar Satish has been regarded as the most productive author, with Khan, Li, Park, and Zalud following closely behind. The Technical University of Kosice is the most prolific institute, followed by the Brno University of Technology and the Chalmers University of Technology, which are placed second and third, respectively.

Finally, 47 papers were extensively reviewed, and an IHC framework was proposed based on the relevant study. Our proposed framework revealed that six key components such as scheduling issues, security, COVID-19, digital supply chain, blockchain technology, and artificial intelligence are needed to be taken into account to evaluate the current healthcare system. Additionally, some unresolved issues, such as reducing the carbon footprint, improving health care for aging populations, and securing long-term supplies during the pandemic, need prompt action. According to the referenced research, data security, identity, and authenticity are still significant concerns in IHC. Researchers and practitioners may consider the limits identified in this paper as the area of future research. In addition, future work might include but is not limited to explainable machine learning-based patient records, procedures and ethics for sharing patient data in cloud systems, and efficient machine learning and deep learning-based resource allocation in healthcare systems.

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