

# Industry 4.0 Enabling Technologies Application in Healthcare Areas - A Systematic Review

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**Abstract:** Healthcare sector makes use of technological advances to develop value to its processes and offers excellence, safety and accessibility services to patients, workers, healthcare operations and quality management. Thus, Industry 4.0 enabling technologies provide benefits in the management of services and healthcare. This study aims to identify researches that show possible applications of Enabling Technologies of Industry 4.0 in the healthcare area. This research work carried out a bibliographic review of articles that investigated applications of Industry 4.0 enabling technologies of in the field of Health. The selected studies deal primarily with the application of Industry 4.0 Enabling Technologies for activities related to data management, analysis, treatment and sharing healthcare information. The contribution of this study focuses on providing information on the advances of Industry 4.0 and its technologies enabled in the healthcare sector, allowing the prospecting of new opportunities for action and applications of technologies that already exist in the healthcare context.

**Keywords:** Industry 4.0, Healthcare, Enabling Technologies.

## 1. Introduction

The use of technological resources is increasing day by day in modern life, allowing greater access to information and services during the search and generation of data that allows companies to understand its customer's profile, therefore effectively meeting expectations. The healthcare sector is not oblivious to this scenario, and requires even higher levels of excellence, safety and accessibility. Moreover, it is necessary to present innovative solutions in the medical industry and in patient-care services.

The growth and aging of the world population, increases the demand for more assertive, less expensive and more accessible resources and healthcare services. Healthcare data and is essential to generate information that can be used to improve resource allocation in service delivery, developing the medical system in order to serving global and local needs of the population [1].

In this sense, healthcare has to present technological advances that add value to their processes and enables greater knowledge for decision-making. These advances are achieved through the application of enabling Industry 4.0 Technologies on health. The use of Industry 4.0 Technologies in healthcare provides interconnectivity and data integration, equipment and personnel. It promotes opportunities to provide, among other benefits, customized products and services and real time data monitoring.

One of the Industry 4.0 Enabling Technologies, Big Data, comprises technological developments in reference to data analysis from different sources, formats and backgrounds, turning them into relevant information to industries and clients. Other Industry 4.0 Enabling Technology is the Internet of Things (IoT) that allows connectivity between different infrastructures, such as digital communications sensors and machines, facilitating transmission and data storage [1]. Cloud computing, also an Enabling

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Technology of Industry 4.0, consists in a platform with ample storage capacity, sharing and accessibility of data that is independent of resources and physical infrastructure.

Industry 4.0 also abhors Cyber-Physical Systems (SPC), which comprises computational, physical and online processes, creating a bridge between incorporated applications, network resources and human body dynamics through the use of inter- and intra-connectivity [4]. Also presented as Enabling Technology of Industry 4.0, Augmented Reality, represents integration between virtual data and real world dimensions through the use of display devices that continuously show the data overlap from both physical and virtual realities [5].

The enabling technology that aims to produce customized items [6] generated from digital data is called Additive Manufacturing, known as 3D printing [7]. Unlike the production of physical items, Artificial Intelligence provides decision-making by machines, simulating the human capacity to organize information and recognize the most adequate decision on solving specific problems.

Considering these technological advances, this investigation suggests the following research questions: (i) which Industry 4.0 enabling technologies are used in Healthcare?; (ii) how have publications on this topic increased over the years?; (iii) how is the distribution of publications by countries?; (iv) which journals most published this topic?; (v) what methodologies and approaches were used in the researches?

To answer the mentioned questions, this study presents a bibliometric review of the literature to identify Industry 4.0 Enabling Technologies applications in Healthcare areas. This paper is organized in structured sections as follows: section 2 presents the aim of the work, in section 3 are described the research methods, section 4 contains the results and, in section 5, the conclusion.

## 2. Objective

This study aims to identify the applications of Enabling Technologies of Industry 4.0 in healthcare areas by means of literature research.

This work will provide the synthesis of academic studies that address research on the topic. It will also present which of the technologies adopted by health services and which are the application proposals, correlating health areas where the proposals of the selected studies were developed.

## 3. Methods

This study presents a literature review on the implementation of Enabling Technologies of Industry 4.0 applied in the fields of Health. A bibliometric survey of visas quantifies the scientific literature on a specific topic [8], through which it is the possible average to identify the data empirical data that can be displayed in predefined selection settings [9]. The synthesis of the results provided by a bibliometric research carried out in a systematic way can be reproduced [10]. The presentation of a compilation of relevant information on a given subject becomes strategic for future studies that address the researched topic [11]. The studies that fit the research theme will be selected, mapped, aggregated and related in a summarized way.

To ensure coverage of the issue upon existing publications, parameters were established to carry out the literature search of all published articles that address the use of Enabling Technologies Industry 4.0 in the context of health. This way, not only keywords and their cognates were defined, but were also established the search basis and the selection benchmark for systematic reviews regarding health: "Health", "Care," "Medical" and "Clinical".

As for Industry 4.0 Enabling Technologies, in agreement with [12] the following keywords were established: "Industry 4.0", "Internet of Things," "Big Data", "Cloud Computing", "Cyber Physical Systems", "Collaborative Robots", "Additive Manufacturing", "Augmented Reality" and "Artificial Intelligence".

The combination of keywords resulted in 36 groups with two terms, one keyword related to Industry 4.0 and the other to healthcare. The search on databases focused on articles that mentioned the selected keywords in its Title, Abstract or Keywords. In addition, this study assumes as a premise, scientific and review articles published in international journals. The analysis on articles took two months, August and September 2019.

This investigation found 679 articles. From this total, 252 duplicated papers have been removed [9]. Others 283 articles were out of the scope of this research. Then, the full-text content analysis involved 144 articles, addressing the application of Enabling Technology of Industry 4.0 in healthcare. As recommended by [13], two researchers led the content analysis of the articles, in order to guarantee reliability to the review.

The analysis consisted in the following topics:

- (i) Publication over the years;
- (ii) Publication's Country of Origin;
- (iii) Periodic where articles were published;
- (iv) Methodology;
- (v) Industry 4.0 Enabling Technologies applied to health;
- (vi) Healthcare areas where were applied the Enabling Technologies Industry 4.0.

## 4. Results

This section shows the obtained bibliometric data after analysis of 144 selected articles, which addressed the application of Industry 4.0 enabling technologies in health.

### 4.1 Publications over the years

The gradual increase of publications addressing the application of Industry 4.0 of Enabling Technologies in healthcare areas care over the years was evidenced. Considering the official designation of the term "Industry 4.0" in 2011 as well as the technologies that demonstrate advances related to this term, is evident that academic publications were more constant from the year 2013 onwards. Therefore, it is possible to consider the scientific community engagement to conduct a research that addresses the application of Enabling Technologies of Industry 4.0 in healthcare areas.

One has to consider that, despite the recent definition of "Industry 4.0", publications prior to 2011 showed Enabling Technologies studies, representing 6% of the selected works. Thus, the reduced number of publications in 2019, compared to the year 2018, can be related to period of time in which the articles were searched, finalized in September 2019. Publication distribution over the years is presented in Fig. 1.

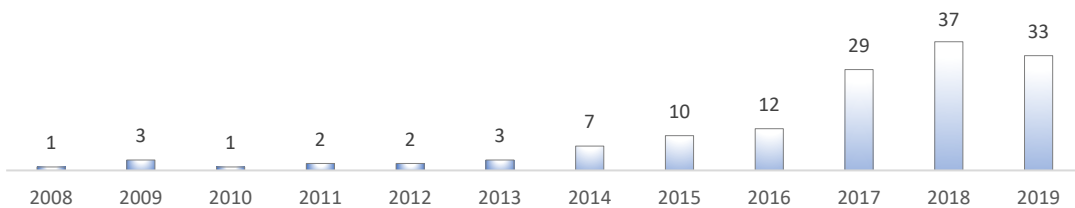


Fig. 1. Publications over the years

### 4.2 Publication's Country of Origin

They were selected arising publications from 32 countries, namely Algeria, United Arab Emirates, Slovenia, Hungary, Israel, Mexico, Poland, Kenya, Singapore, Tunisia, Vietnam, Belgium, South Korea, Egypt, Finland, Greece, Saudi Arabia, Canada, Korea, Iran, Japan, Italy, Germany, Spain, France, India, Brazil, Australia, United Kingdom, China and the United States.

Note that the United States studies were significant, publishing 30 articles on the topic, followed by China and the United Kingdom, with 21 and 15 publications respectively. Countries that had more than 4 publications related to the topic are represented in Fig. 2.

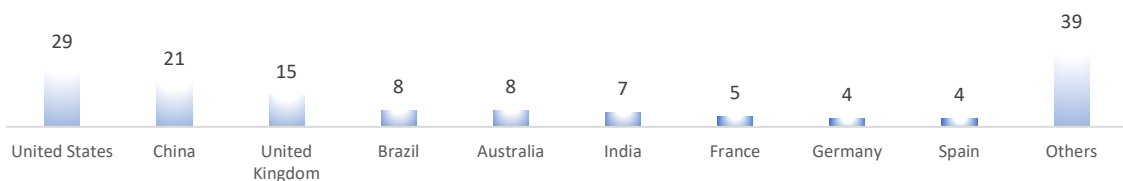


Fig. 2. Publications by country

### 4.3 Journals

The selected articles were published in 87 different journals, 68 of them having only one publication about the subject and 18 having 2 or more publications. Journals represented in Fig. 3 presented three publications or more. The journal "Future Generation Computer Systems" accounted for 13 selected publications.

Ratings for journals were not established, as they take on different lines of publication. Journals about health, information technology, dentistry and other segments were selected, indicating a sprayed approach of the themes through different areas of interest in the application of Enabling Technologies of Industry 4.0 in healthcare areas.

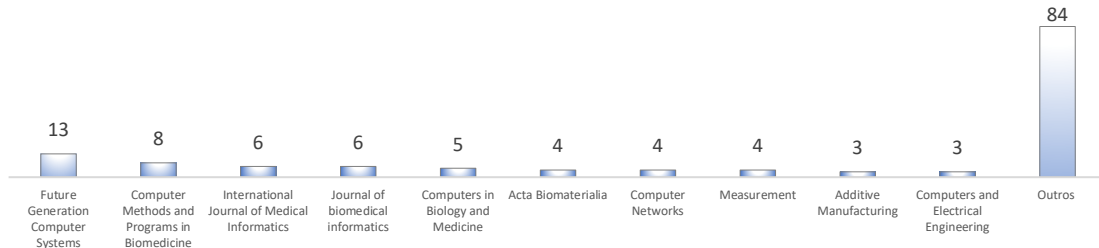


Fig.3. Publications by journal

#### 4.4 Applied Methodology

The selected papers presented mostly experiments and case studies as the research methodology of choice, which is justified since they are recent themes and they are considered innovative initiatives, according to the found literature. Similarly, the representation of literature researches, showing the scientific community's interest in more information on the Industry 4.0 Enabling Technologies and their applications in healthcare areas. 2% of the selected articles showed surveys, also related to scarcity of Healthcare initiatives that can be evaluated and compared in large volumes. 54% of the selected works presented qualitative approaches with the intention of providing information based on particularities of each studied case.

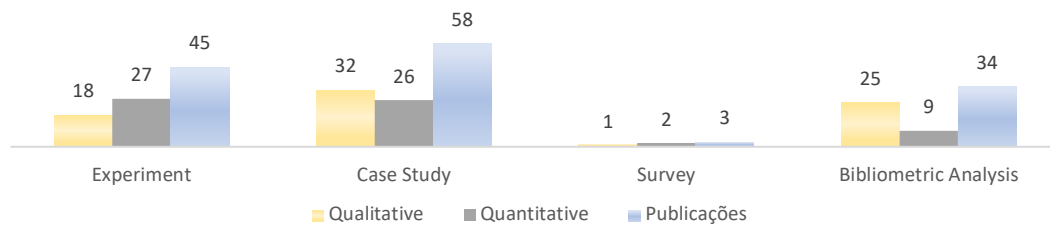


Fig. 4. Methodology and Research Approach

#### 4.5 Industry 4.0 Enabling Technologies in Healthcare Areas

The literature review conducted by this research identified the following Industry 4.0 Enabling Technologies applied in Health: Big Data; Internet of Things; Cloud Computing; Cyber-Physical Systems; Additive Manufacturing and Artificial Intelligence. None article mentioned the use of Collaborative Robots in healthcare.

Big Data had presented in the most of studies. This technology is characterized by the large amount of data available and their potential use for analysis. Thus, the electronic medical records allows easier access to medical data, which analyses can afford more knowledge about patients profile [14], generate guidelines for strategic objectives in health institutions [15] and address clinical approaches related to lines of care [16] [17]. In addition, Big Data was useful for the identification of disease outbreaks [18], epidemiological research related to cardiac clinical conditions of patients [19] and clinical impacts resulting from radiological treatments in cancer patients [20]. Furthermore, to guarantee the high quality of collected data [21] and their comparative analysis [22].

The treatment and interpretation of a large amount of data allowed health services to use the available information to pathologies diagnoses. It was applied on treatment of patients with breast cancer [23], lung cancer [24], arthrosclerosis [25], gestational diabetes [26] and Alzheimer [27]. It was also used to identify patients with clinical characteristics of epilepsy [28], heart disease [29], fatty liver [30], dyspepsia [31] and rare diseases with specific characteristics [32]. In addition, the structuring of algorithms for data interpretation was used to identify allergic reaction to medicines [33] and the interpretation of abnormalities in electrocardiological exams [34] and mammographic test exams [35], in order to treatment delays.

Moreover, the definition of algorithms applied to health data allowed the prediction of diseases through interpretations of current clinical conditions. It presented trends in the evolution of patients to bipolar disorder [36], suicide resulting from disorders of mood [37], prediction of heart disease [38], anaphylaxis [39], psychiatric disorders [40], lung cancer [41] and pandemic disease prediction [42]. Three studies evaluated patients' clinical conditions by monitoring their vital signs of patients using available medical data [43], [44] [45]. In order to make it possible to use Big Data in health institutions, it is necessary to provide adequate structures and resources [46], which involve mechanisms for adequate allocation of technological resources for health [47] [48], mechanisms for data collection [49], data analysis [50] and treatment of health data [51]. Since medical records present confidential patient data, security issues against data breaches were addressed [52] [53], also the need to protect genomic data [54], and obtained data by smartphone applications [55], through cryptography [56].

Internet of Things (IoT) is also an Industry 4.0 Enabling Technology identified in articles. The system integration to share medical data means the application of IoT in healthcare. Structure-related issues highlighted the need for resources to optimize real-time transmissions [57], ensuring immediate data storage and processing [58] [59], as well as mechanisms for immediate interpretation of information [60]. There was also an approach on the optimization of these structures aiming at the integration of systems at low costs [61]. The main health IoT application were related to real-time monitoring of patient data using mobile and wireless sensors to track vital signs [62] [63] [64], elderly related risks [65] [66] or for outpatient prenatal management of pregnant women [67]. Basic nursing care can be optimized by using IoT [68], as well as monitoring patients during exercise [69], during rehabilitation procedures [70], tracking their location [71] and monitoring patients to prevent sleep apnea [72]. With real time data monitoring, studies addressed the application of IoT identify cancer diagnosis [73] [74], interpretation of imaging tests [75] and detection of stroke detection [76]. Studies addressed prediction of heart disease [77] and the risks of cancer mortality [78]. This information help in allocating resources through demand forecasting [79]. In addition, studies approached security of shared information against data breaches [80] [81], using cryptography in mutual information transference [82], with a focus on data authentication [83], traceability of data sources in real time [84] [2] and data sharing in a safe and cost-effective manner [85]. The application of IoT technologies supported the structuring of the concept of intelligent health [86].

Other technology, Cloud Computing, provides robust data storage capabilities to make easier the transmission and sharing of information without relying on hardware support. Data storage also requires resources to ensure the reduction of network latencies [87] that allow the receipt of data in real time [88] [3], as well as the transmission and monitoring of this data [1]. Cloud Computing can make available the access to medical data in distant regions [89] [90] using different data formats [91] in favor of improvements in health [92]. The security of information stored on the desktop is also addressed in relation to the security of servers [93] during data sharing [94]. When data sharing happens across national borders, attention and regulation are needed to maintain security of security [95]. In addition, Cloud Computing was presented as a important tool on real time monitoring patients [96], detect clinical abnormalities, predict future trends [97], definition of mosquito-borne diseases [98] and an identification of cancerous lesions [99]. Disease prediction was associated with cloud data analyses [100], which can predict the occurrence of cancer [101] health-shocks prediction [102]. The storage of historical health data allows drug traceability [103] and medication therapy adherence [104]. Studies presented perspectives for the application of this technology in health [105] [106], as well as studies on users' perception of this technology [107].

Furthermore, Additive Manufacturing has a notoriety by 3D printing. This technology presents health applications related mainly to the development of medical implants [108]. Several studies have presented the possibility of producing synthetic bone tissue [109], reproducing the porosity of the bone structure [110] and on the possibility of using various materials to develop medical implants. Metallic additives for surgical implants [111], metallic and ceramic for dental restorations [7] [112] and gypsum-sisal fiber composites [113] were addressed. The studies also related mechanical characteristics necessary to produce medical implants [114], as adequate porosity [15] and adequate softness for peripheral nerve repairs [116]. Optimizations and improvements in the production process are addressed in terms of image segmentation for the manufacture of medical implants [117] and printing of dental restorations [118]. Topics about material biocompatibility [119], toxicological evaluation [120] bacterial resistance [121] and contamination levels [6] highlighted the search for safe and personalized health products. Was presented the production of printed capsules was obtained by an Additive Manufacture, whose time and place of absorption could be calculated [122]. 3D impressions can contribute to medical education through the production of anatomical models [123], being used to develop student's skills facing of simulations of real clinical conditions [124] [125]. Such simulations can also support pre-operational planning [126] [127].

Augmented Reality was presented in medical education initiatives as a technology used to simulate surgical procedures, such as a arthroscopy [128], dental surgeries [129] and general anatomical studies, allowing the development of medical skills [5] [130] and guaranteeing prior knowledge of surgical procedures, enabling less invasive procedures [131]. Real time additional clinical information during surgical procedures [132] were performed in spine surgery, [133] interstitial brachytherapy [134], radical prostatectomy [135] and hepatobiliary surgery [136]. Preoperative planning through augmented reality analyzes has been reported [137], as in thermal liver ablation [138]. Augmented Reality allowed training new surgical techniques [139], surgery assisted by robots [140] and surgical tele collaborations in real time [141]. The availability of virtual information in the real environment allows increasing the information related to safety on the use of medical equipment [142] and support to medical professionals in neuropsychological assessments of elderly patients at risk of dementia [143].

Other two technologies, Cyber-Physical Systems and Artificial Intelligence, contributed to advances in medical area. Cyber-Physical Systems in the health area, initiatives to ensure security against data breaches in cyber environments [4] were addressed, also applications of this technology on three-dimensional monitors in health environments [144]. Artificial Intelligence (AI) was helpful in sports medicine to identify risks of muscles trauma [145]. Moreover, decision-making through A.I to forward alarms and personalized suggestions to patients' adherence to drug therapy according to the analysis of medication withdrawal from the monitored storage location [146].

The bibliometric analysis of articles addressed as Enabling Technologies in Industry 4.0 is shown in figure 5. The quantity of studies in healthcare areas is shown in figure 6.



Fig. 5. Enabling Technologies of Industry 4.0 addressed

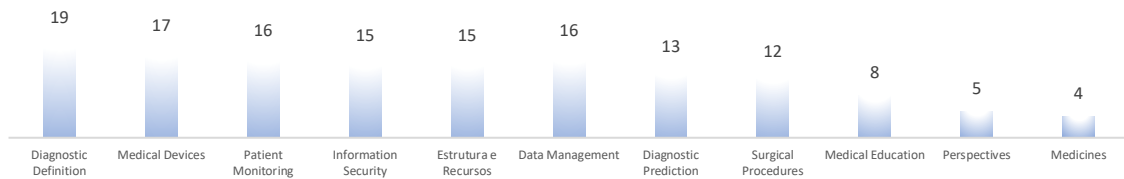


Fig. 6. Segment in Healthcare Area

## 5 Conclusion

The reviewed literature revealed initiatives carried out on the implementation of Industry 4.0 Enabling Technologies in healthcare areas. The selected studies mainly address the use of data in order to characterize and predict clinical diagnoses as well as real time patient monitoring. The most frequently addressed Industry 4.0 Enabling Technology are, likewise, associated with data management: Big Data, Cloud Computing and Internet of Things.

The contribution of this study is related to structured provision of information on the progress of Industry 4.0 Enabling Technologies and the correlation between its main intrinsic features and major contributions to healthcare. It is relevant to professionals and healthcare organizations to prospect new opportunities for action and application of existing technologies in the healthcare context in which they are involved. This study was limited due to the lack of literary agreement on the definition of Industry 4.0 Enabling Technologies, being that eight technologies were used when searching. Thus, the recommendation for further research is recommended to be carried out directed to specific areas of healthcare, searching by sectors, specialties and specific diagnosis.

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