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# Healthcare 4.0: trends, challenges and research directions

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**ABSTRACT**

This paper aims at examining the trends, challenges and theoretical gaps in the implementation of Healthcare 4.0 (H4.0) based on a scoping review of the literature. For that, we searched journal articles in four widely known databases and screened the retrieved articles to obtain a publications' portfolio. Our findings indicate that, despite the recency of the subject, research in H4.0 has been conducted in an interdisciplinary way with a diversified set of applications and functionalities. In terms of its implementation, H4.0 has been more commonly found in hospitals' information flows, especially the ones related to healthcare treatments. The identified implementation trends, however, neglect a more holistic approach for H4.0, which originated three main research directions for this topic. Although identified as a trending topic in the area of healthcare operations management, literature on H4.0 may be viewed as randomly conceived, lacking academic alignment and practical orientation based on a grounded theory, which we aim at providing with the present study.

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**KEYWORDS**
Healthcare 4.0; smart healthcare; healthcare operations management; literature review

## 1. Introduction

With the advent of the Fourth Industrial Revolution, also known as Industry 4.0 (I4.0), novel information and communication technologies (ICTs) have been incorporated into organisations to facilitate and support more efficient and flexible processes, services and products (Liao et al. 2017; Xu, Xu, and Li 2018). I4.0 is characterised by a higher level of interconnectivity between cyber and physical elements (Cyber-Physical Systems – CPS) and inter-related solutions enabled by disruptive ICTs, such as Big Data, Internet of Things (IoT) and Cloud Computing (Lasi et al. 2014). As the interest on the topic has significantly grown over the past few years, researchers have expanded I4.0 concepts and principles, and envisioned benefits that go beyond the manufacturing industry context, such as cities (Lom, Pribyl, and Svitek 2016), homes (Branger and Pang 2015), products (Lu 2017), and healthcare systems (Manogaran et al. 2018).

When integrated into healthcare systems, I4.0 technologies originated the term Healthcare 4.0 (H4.0), which is argued to enable real-time customisation of healthcare for patients, professionals and caretakers (Thuemmler and Bai 2017). More specifically, the adoption of H4.0 facilitates the shift from hospital-centered to patient-centered organisations, in which different departments, roles and responsibilities are integrated towards the best patient health outcome (Alloghani et al. 2018). Despite its benefits, Wolf and Scholze (2017) emphasise that there are still significant barriers imposed by political and economic interests, as well as demands from organisations, associations and lobbyists, to fully integrate novel technologies into healthcare. Additionally, Aceto, Persico, and Pescapé (2018) mentioned that most studies provide a narrow perspective on the application of ICT in the healthcare context, falling short of providing a more holistic view on the subject. Despite its increasing notoriety, literature evidence on H4.0 may be viewed as randomly conceived, lacking academic alignment and practical orientation based on grounded theories (Yang et al. 2015). Such misalignment and randomness on H4.0 research prevent from clearly grasping implementation trends and challenges, entailing conceptual confusion and theoretical spraying of the topic.

To address such issue, this paper aims at examining the trends, challenges and theoretical gaps in the implementation of H4.0 based on a scoping review of the literature. A scoping study is recommended to identify and map key concepts that underpin a certain research topic, especially when it has not been reviewed comprehensively before (Mays, Roberts, and Popay 2001; Peterson et al. 2017). The scoping review approach is also suggested as an alternative to a systematic review when literature is vast, sparse and complex (Arksey and O'Malley 2005; Grimshaw 2008), which is the case of H4.0 (Pan et al. 2018). With that in mind, we present the results of a scoping study on H4.0, consolidating implementation trends and challenges according to different categories of interest, identifying theoretical gaps in the existing literature and proposing future research directions aimed at bridging those gaps.

## 2. Fourth industrial revolution and healthcare

The growing demand for more efficient, qualified and less expensive health services has motivated novel solutions in

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the healthcare sector (Dehe and Bamford 2017). Led by the advent of Internet, ICTs started playing a key role as enhancers of efficiency and quality in healthcare systems in the 1990s, culminating in what is currently known as 'e-health' (Aceto, Persico, and Pescapé 2018). Wolf and Scholze (2017), Kang et al. (2018) and Kumari et al. (2018) compared the industrial revolution era to the evolution of healthcare systems. For instance, healthcare initially relied on the expertise of doctors and the utilisation of a limited number of drugs derived from natural substances. Subsequently, based on the advent of antibiotics and imaging diagnostics, a second healthcare revolution took place. Later, with the introduction of microsystems technology and electronics (e.g. navigated surgery and image recognition) into surgery procedures, a third era was originated. Currently, healthcare systems are moving into an H4.0 era, characterised by an increasingly level of interconnected ICTs, electronics and microstructure technology that enable more efficient therapeutic structures and supporting processes (Sultan 2014; Yang et al. 2015). To Prieto González et al. (2016) some advances have increased the feasibility of H4.0; namely: (*i*) availability of new effective and cheaper ICTs with the ability to diagnose and provide immediate results and solutions; (*ii*) reduction on ICT dimensions (e.g. sensors) facilitating their portability; and (*iii*) higher capacity of acquiring and managing large quantities of data.

Emerging principles and technologies encompassed by I4.0 have been extended to H4.0 as a continuous (although disruptive) process of innovation and transformation of the entire healthcare value chain (Pramanik et al. 2017). Alloghani et al. (2018) emphasise that H4.0 allows physicians, nurses and other hospital staff to offer and benefit from internal and cross-hospital services in a more efficient way. Evidence on applications of novel ICTs in healthcare may vary according to two prevalent domains (Oueida et al. 2018): health treatments and hospital supporting processes. The former refers to treatments that patients may undergo according to their specific needs, such as chemotherapy (Wolf and Scholze 2017), gastro internal tract diagnostics and therapy (Ciuti et al. 2016), and surgical practices (Malik et al. 2015); the latter represents managerial processes that are supposed to support patients' care, such as medical consumables or devices (Ali et al. 2018), financial transactions (Alharbi et al. 2016), equipment maintenance (Gómez and Carnero 2011) and the management of drugs (Agha 2014). In general, Das, Yaylacicegi, and Menon (2011) suggest that ICTs applied to health treatments may positively affect hospitals' outputs in the short term, while their application on administrative and supporting processes may display an incremental influence in the long run.

Finally, a clarification on the concept of healthcare system is necessary. The World Health Organization (2007) defines health systems as all organisations, people and actions whose primary intent is to promote, restore or maintain health. This includes efforts to influence determinants of health as well as more direct health-improving activities. It includes, for example, a mother caring for a sick child at home, private providers, behaviour change programmes, occupational health and safety legislation, among others. However, health system has been often defined with a reductionist perspective (Frenk 2010), and its concept has also been associated with additional dimensions, such as: (*i*) it should not be expressed in terms of its components only, but also of its interrelationships; (*ii*) it should include not only the institutional or supply side of the health system, but also the population; (*iii*) it must be seen in terms of its goals, which include not only health improvement, but also equity, responsiveness to legitimate expectations, respect of dignity, and fair financing, among others; and (*iv*) it must also be defined in terms of its functions, including the direct provision of services (whether they are medical or public health services), but also other enabling functions (e.g. stewardship, financing, and resource generation). Such diversified conceptual definition entailed the adaptation of healthcare systems around the world in accordance with regional needs and resources (White 2015). Due to this mixed understanding of what truly comprises a healthcare system and to mitigate any theoretical variability, our study focussed on literature evidence that approached the integration of new digital technologies into both hospitals and medical clinics.

## 3. Research method

Our research method followed scoping study procedures proposed by Arksey and O'Malley (2005), being comprised of five steps: (*i*) identify the research questions, (*ii*) identify relevant studies, (*iii*) select studies, (*iv*) chart the data, and (*v*) collate, summarise and report results.

### *3.1. Identify the research questions*

Initially, we identified relevant aspects of H4.0 that would motivate the research questions and guide the search strategies adopted in the study (Khan et al. 2001). The technological integration into healthcare systems has been evolving throughout the past decades (Fosso Wamba and Ngai 2015; García-Villarreal, Bhamra, and Schoenheit 2019), with a distinguished relevance after the acknowledgement of the fourth industrial revolution. Since H4.0 is a relatively recent concept whose implementation has occurred in a sparse and narrow way, mainly targeted at ICTs (Yang et al. 2015), processes (Shi et al. 2016), health treatments (Amin et al. 2019) and desired results (Rghioui and Oumnad 2018), we propose the following research questions:

> *RQ1*. What are the main ICTs adopted to promote H4.0 in healthcare organizations?

> *RQ2*. What has been the focus of H4.0 implementation in those organizations?

> *RQ3*. What are the main barriers and contributions of H4.0 adoption?

Research questions were formulated to support a wide and comprehensive literature search, as recommended by Mays, Roberts, and Popay (2001). To answer those questions

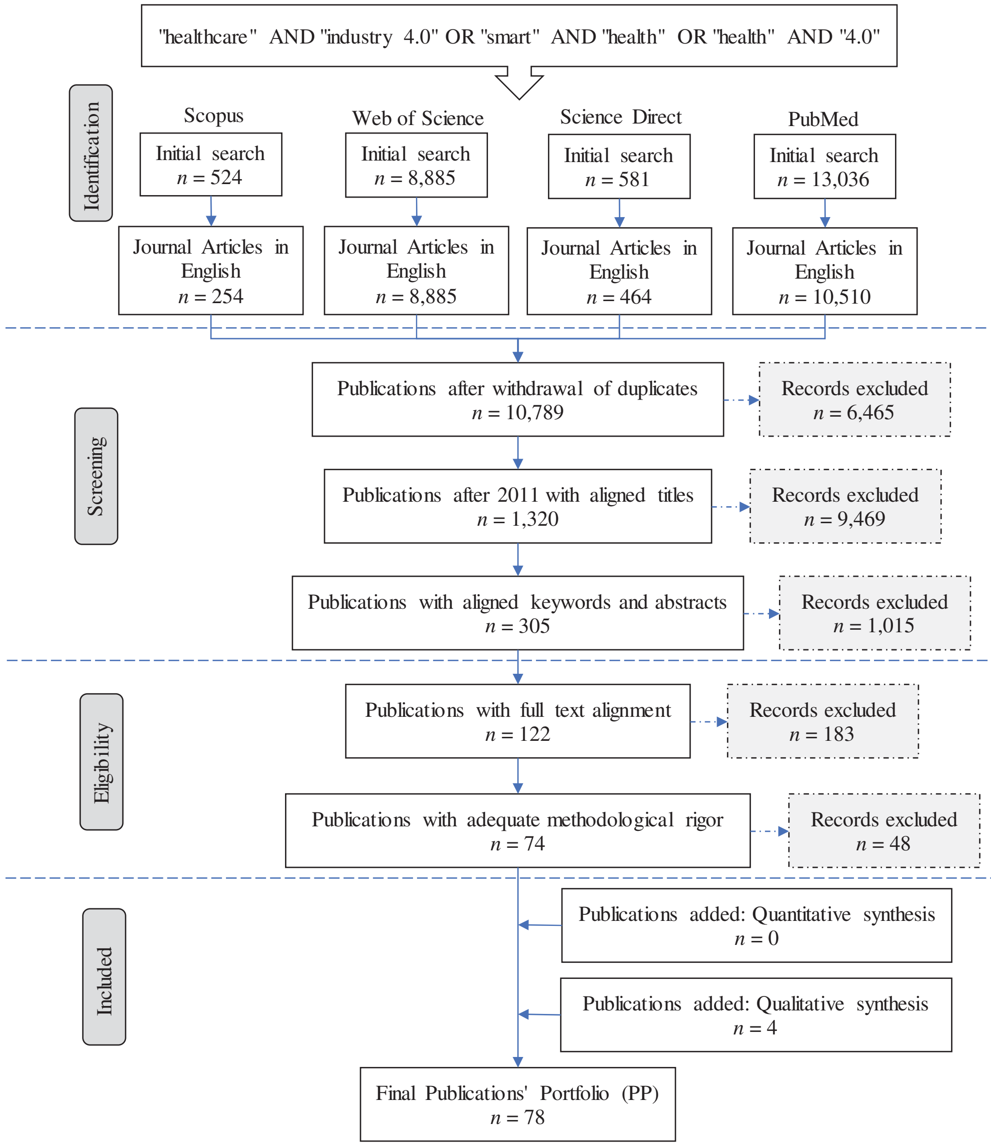

Figure 1. Selection of studies to be included in the review.

a rigorously structured and sufficiently documented method was carried out, to provide robust evidence and arguments.

### 3.2. Identify relevant studies

A scoping study requires the identification of all relevant literature, regardless of methodological design (Peterson et al. 2017). Since familiarity with the research topic is likely to increase as the review is carried out, the search for relevant studies was conducted in two stages. This process allows us to address the potential problem of the search string being overly specific or entailing (partially) misleading buzzwords.

First, we defined two research dimensions that were related to our research questions; they were: healthcare and industry 4.0. An initial set of keywords ('healthcare' AND "industry 4.0' OR 'health' AND '4.0') was combined to retrieve publications that used them in the title, abstract and/or keywords. The use of the AND operator in the search process, significantly reduced the occurrence of misleading results, especially in the case of the string '4.0'. As recommended by Augusto and Tortorella (2019) who developed a similar study in the healthcare sector, we searched for scientific articles in the following databases: Scopus, Science Direct, Web of Science and PubMed (that comprises biomedical literature from MEDLINE, life science journals and online books). Since the first stage aimed at validating the chosen keywords, no filtering criteria were applied to the search. A total of 15,506 publications were retrieved from all databases.

In the second stage we randomly selected five articles from each database to compare their keywords with the ones from the research dimensions used in the first stage (Borges et al. 2019). Since the investigated topic is recent in the literature different taxonomies may be associated to a given subject, potentially compromising the search. From the comparisons we identified the need to add another combination of keywords to our search: 'smart' AND 'health'. A second search including those keywords returned a total of 23,026 publications, scattered among the databases as informed in Figure 1. Both search stages reported here were conducted between March and April 2019.

### 3.3. Select studies

The selection of studies was concurrently conducted by two of the authors, as recommended by Munzer et al. (2019). Similarly to Peterson et al. (2017), we followed the standard Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which is comprised of four stages (Moher et al. 2009): (*i*) identification, (*ii*) screening, (*iii*) eligibility, and (*iv*) inclusion. Different inclusion/exclusion criteria were devised *post hoc*, as the researchers' familiarity with the literature increased. Firstly, we considered only articles in English published in peer-reviewed journals. Duplicate publications were withdrawn from the portfolio, which reduced from the initial 23,026 to 10,789 articles. Next, titles were verified regarding alignment with the research topic. Since H4.0 derives from principles and technologies from I4.0 whose concept was formally acknowledged in 2011 (Lasi et al. 2014), we only considered publications after this year. Further, in the literature review study widely referenced of Liao et al. (2017), authors indicated that, even though the announcement of the I4.0 concept traces back to the April of 2011, it began to attract attentions only after it became one of the ten official projects within the 'High-Tech Strategy 2020' action plan in March of 2012. In this sense, no study was identified before this period, supporting the establishment of the cut-off year assumed in our scoping review. The 1,320 articles that passed the title screening and were published after 2011 were then checked for alignment of keywords and abstracts with the research topic, completing the screening stage and resulting in 305 articles.

In the eligibility stage a full text analysis of these 305 articles was carried out, and 122 articles were identified as fully aligned with our research interests. Articles were then evaluated regarding criteria of relevance and methodological rigour; those deemed uncertain with respect to any criterion were reviewed by the third author, and a decision was made by majority vote. By the end of this stage 74 publications were considered appropriate to be included in our review. References in these articles were examined to identify relevant studies mentioned but not yet included in the portfolio. No studies were included after this quantitative analysis; however, four publications were added based on experts' recommendations (qualitative analysis). In total, 78 studies were selected to compose the final publications' portfolio (PP), as displayed in Figure 1.

### 3.4. Chart the data

This step aims at charting and interpreting key data from the PP to establish the grounds for the subsequent analytical step (Levac, Colquhoun, and O'Brien 2010). We followed a descriptive analytical method (Khan et al. 2001; Arksey and O'Malley 2005), providing a broader and meaningful view of all PP and collecting standard information from each study. Given the purpose of our study, articles were organised in a spreadsheet including the following information: authors, year of publication, location where the study was conducted, journal, aims, ICTs, application focus (e.g. hospital processes or health treatments), challenges and opportunities.

### 3.5. Collate, summarise and report results

In this step results are collated, summarised and reported based on a thematic framework, such that a narrative account of the PP becomes available. Following indications by Levac, Colquhoun, and O'Brien (2010), three complementary analyses were carried out to increase the consistency of this step.

First, to collate and summarise results we performed a descriptive numerical summary and a thematic analysis. The summary provided information on key PP characteristics (e.g. total number of studies, publication years, studies' location), helping to address *RQ1* and partially answering *RQ2*; the thematic analysis allowed a qualitative examination of articles' contents according to healthcare processes and treatments, providing a more holistic perspective on how H4.0 is being implemented, and complementing the answer to *RQ2*. The thematic analysis also helped reporting and categorising H4.0 challenges and opportunities according to the focus of application within the healthcare system, raising arguments to support *RQ3*.

Second, based on reported results we proposed an H4.0 implementation framework, further detailed in section 4. Finally, we discussed the implications of our findings in a broader context ensuring the legitimacy of the scoping study methodology for both theory and practice (Levac, Colquhoun, and O'Brien 2010). In that discussion we also listed research gaps and proposed an agenda for future studies.

## 4. Results and analysis

Figure 2 displays the descriptive numerical summary of the publications' portfolio. As expected, studies on H4.0 are extremely recent and there is a significant increase in the number of publications in the past two years. The majority of research on H4.0 has been developed in countries such as Canada, India and South Korea. As the concept of I4.0 first emerged in the Hannover Fair in Germany, it would be expected for European countries to stand out with larger number of studies on H4.0; our PP shows otherwise, with the application of novel ICTs in healthcare organisations being predominantly promoted outside the European context.

The PP presents a total of 279 authors; of those 16 participated in two or more studies and the remaining 263 contributed in only one article. That indicates a scattered distribution of researchers without a significant prominence of any author, which is typical of a research topic about which knowledge is still incipient. The background of most researchers is *Computing and Information Technology Science* and *Business Management Economics and Industrial Engineering* (75% and 10%, respectively); only 8% of authors are from *Medicine and Health* fields. Such fact reinforces the multidisciplinary nature underlying the adoption of modern ICTs by healthcare organisations, merging healthcare expertise with technical aspects from computing science and operations management. Journals in which most studies on H4.0 have been published also provide evidence to its multidisciplinary nature; e.g. *IEEE Access*, an application-oriented and interdisciplinary journal. Additionally, aim and scope of most

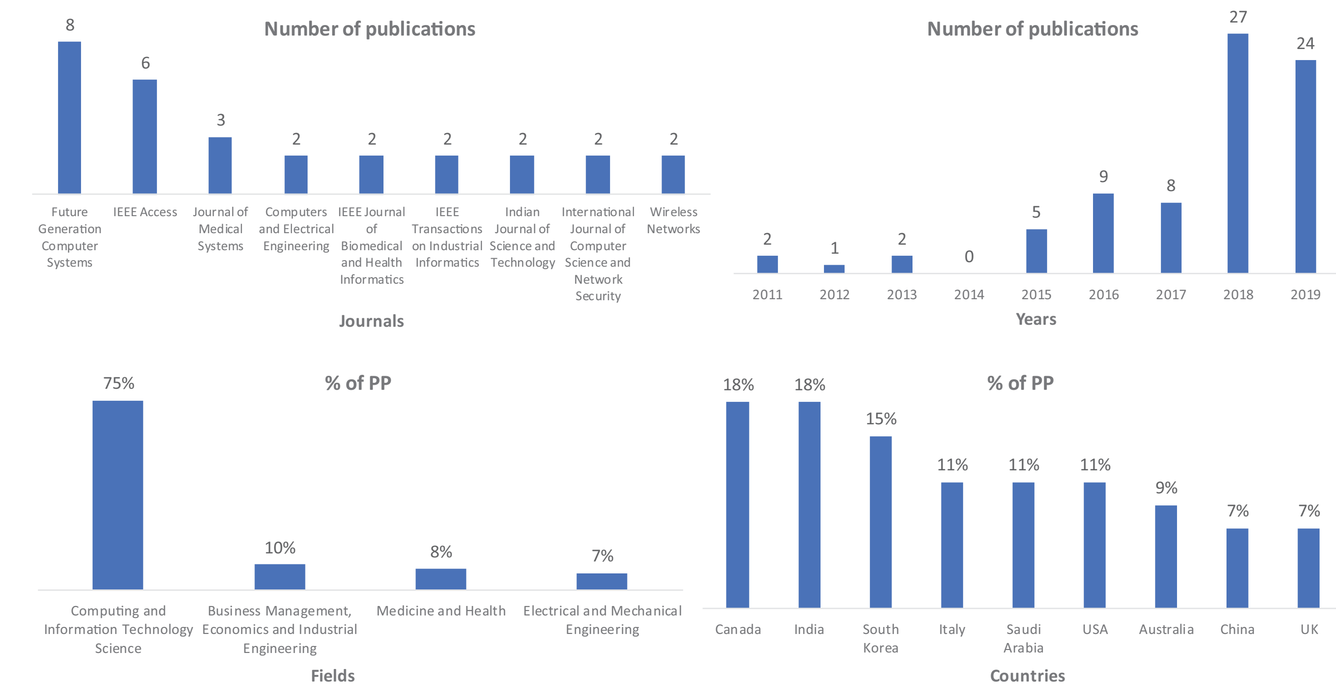


**Figure 2.** Quantitative analysis of the papers in this review.

journals included in the PP cover applications, developments and theory related to ICTs, such as *Future Generation Computer Systems*. That somewhat converges to the recommendation of Demirkan (2013) and Rizwan et al. (2018), who emphasised the need for a holistic perspective when integrating ICTs into healthcare systems.

Regarding the thematic analysis, evidence of ICT applications in healthcare organisations was divided into two groups: those related to (*i*) health treatments and to (*ii*) hospital's supporting/administrative processes. In total, nine main ICTs were found in the PP, as shown in Table 1. Although consistently acknowledged as a means to increase healthcare organisations' efficiency and quality, ICTs vary significantly in terms of purpose and application frequency.

Applications of ICTs in health treatments aimed predominantly at measuring and controlling vital patients' parameters, such as blood pressure (Wan et al. 2018), heartbeat rate (Jeong, Han, and You 2016), physiological biometrics (Hamidi 2019) and body fat (Kim, Jeong, and Park 2016), among others. In those applications, biomedical/digital wireless sensors combined with ICTs that aim at processing (e.g. big data, machine/deep learning) and communicating (e.g. IoT, cloud/fog computing, big data, remote control/monitoring) data appear to be highly useful. In fact, such particular combination of ICTs was also present in other health treatment applications, such as neurological disorders (Alhussein et al. 2018) and cardiovascular diseases (Wang, Huang, et al. 2019). In opposition, the pervasiveness of other ICTs, such as 3 D printing, collaborative robots/robotics and augmented reality/simulation, seems to be much lower, which may be inferred by the smaller number of studies reporting their utilisation in hospitals. The literature on applications of ICTs in hospitals' supporting/administrative processes emphasises the incorporation of H4.0 technologies into disease/drugs' management (Elhoseny et al. 2018) and clinical aspects (Garai et al. 2017). The set of ICTs mainly applied to those processes appears to be the same used in patients' vital parameters measurement. Such result highlights the versatility of combining certain ICTs, such as biomedical/digital wireless sensors, IoT, machine learning, big data, cloud computing and remote control, in terms of applicability. It also indicates that the utilisation of a single ICT may not suffice to support significant enhancements on either administrative processes or health treatments.

We were able to consolidate nine main contributions and benefits derived from the adoption of H4.0, which are given in Table 2. Apart the envisioned operational performance improvements, benefits in hospitals' interactions with patients and stakeholders are also claimed (Wang, Kung, and Byrd 2018). From those, the possibility of improving electronic health record systems ($c_3$) appears as the most predominant, followed by usage of mobile health applications ($c_4$) and improvement on diagnosis and patient care practices ($c_5$). The extensive adoption of modern ICTs is creating new opportunities and applications that may help overcoming traditional challenges in healthcare organisations (Aceto, Persico, and Pescapé 2018). In addition to potential improvements on performance, Wang, Kung, and Byrd (2018) mention the positive impacts of ICTs on the way hospitals interact with patients and stakeholders. However, there seems to be no consensus on the precise contributions to be expected from the adoption of H4.0 in healthcare systems (Bardhan and Thouin 2013; Agha 2014), which is probably related to its still incipient body of knowledge. In fact, previous studies have either theoretically envisioned or empirically evidenced a variety of benefits from ICTs incorporation. Gastaldi and Corso (2012) add that results from process digitalisation in hospitals are highly variable, potentially leading to managerial pitfalls and frustration.

**Table 1.** Most frequently cited digital technologies and their applications in healthcare organisations.

| | Biomedical/digital wireless sensors | 3D printing | Collaborative robots/robotics | IoT | Machine/ Deep learning | Big data | Cloud/ Fog computing | Augmented reality/simulation | Remote control/monitoring |
|---|---|---|---|---|---|---|---|---|---|
| Health treatment | | | | | | | | | |
| Cancer diagnostic and treatment | 35, 41 | | | 10, 35, 41 | 10, 41 | 10, 35, 41 | 10, 41 | | 10, 35, 41 |
| Vital parameters measurement | 1, 4, 5, 6, 8, 12, 13, 14, 15, 16, 17, 18, 26, 31, 34, 38, 42, 44 | | | 1, 4, 5, 6, 8, 12, 14, 15, 16, 17, 18, 26, 31, 34, 38, 42, 44 | 1, 5, 6, 12, 15, 26, 31, 34, 38, 44 | 1, 4, 5, 6, 8, 12, 14, 15, 16, 17, 18, 26, 31, 34, 38, 42, 44 | 1, 4, 5, 6, 8, 12, 14, 15, 16, 17, 18, 26, 31, 34, 38, 44 | | 1, 5, 12, 14, 15, 16, 17, 18, 26, 31, 34, 38, 42, 44 |
| Heart and cardiovascular diseases | 19, 20, 23, 24, 34 | | | 19, 20, 23, 24, 34 | 20, 23, 34 | 20, 23, 34 | 19, 20, 23, 24, 34 | 19 | 19, 20, 23, 24, 34 |
| Emergency medicine | 19, 34, 40 | | | 9, 19, 34, 40 | 34 | 9, 34, 40 | 9, 19, 34, 40 | 19 | 9, 19, 34, 40 |
| Neurological disorders (e.g. epilepsy, stroke and Alzheimer) | 21, 22, 24, 25, 33, 34 | | | 21, 22, 24, 25, 33, 34 | 21, 22, 25, 33, 34 | 21, 22, 25, 33, 34 | 21, 22, 24, 25, 33, 34 | | 21, 22, 24, 25, 33, 34 |
| Diabetes management | 7, 23, 34 | | | 7, 23, 34 | 7, 23, 34 | 7, 23, 34 | 23, 34 | | 23, 34 |
| Surgery and surgical practices | 19, 39 | 28 | 28, 39 | 19, 39 | | | 13, 19 | 19, 28, 39 | 19, 39 |
| Medical images (e.g. tomography, magnetic resonance imaging, radiography) | 29, 30, 33, 43 | | 29 | 29, 30, 33, 43 | 29, 30, 33, 43 | 29, 30, 33, 43 | 29, 30, 33, 43 | 29, 30, 43 | 29, 30, 33, 43 |
| Supporting/administrative process | | | | | | | | | |
| Disease/drugs management | 1, 6, 15, 28, 31, 36 | 28 | | 1, 6, 10, 15, 28, 31, 36 | 6, 10, 15, 28, 31, 36 | 1, 6, 10, 15, 28, 31, 36 | 1, 6, 10, 15, 28, 31, 36 | | 1, 10, 15, 28, 31, 36 |
| Personnel management | 3, 27 | | | 27 | 27 | 27 | 3, 11, 27 | | 27 |
| Hospitality services | 3 | | | | | | 3 | | |
| Clinical aspects | 2, 3, 5, 12, 17, 27 | | | 2, 5, 10, 12, 17, 27, 32 | 5, 10, 27, 32 | 5, 10, 17, 27, 32 | 2, 3, 5, 10, 11, 17, 27, 32 | | 5, 10, 12, 17, 27, 32 |
| Financial management | 3 | | | 10, 32 | 10, 32 | 10, 32 | 3, 11, 10, 32 | | 10, 32 |
| Medical consumables' management | 3, 17 | | | 10, 17 | 10 | 10, 17 | 3, 10, 17 | | 10, 17 |
| Scheduling systems | 11, 27, 37 | | | 10, 11, 27, 37 | 10, 11, 27, 37 | 10, 11, 27, 37 | 10, 11, 27, 37 | 37 | 10, 11, 27, 37 |

*Authors:* 1-Jeong, Han, and You (2016); 2-Garai et al. (2017); 3-Ali et al. (2018); 4-Sannino, De Falco, and De Pietro (2019); 5-Hamidi (2019); 6-Elhoseny et al. (2018); 7-Neborachko, Pkhakadze, and Vlasenko (2018); 8-Manogaran et al. (2018); 9-Oueida et al. (2018); 10-Demirkan (2013); 11-Yi and Cai (2019); 12-Uddin (2019); 13-Yang et al. (2015); 14-Pace et al. (2019); 15-Hassan et al. (2019); 16-Peng et al. (2017); 17-Catarinucci et al. (2015); 18-Yang et al. (2016); 19-Munzer et al. (2019); 20-Wang, Huang, et al. (2019); 21-Alhussein et al. (2018); 22-Amin et al. (2019); 23-Priyadarshini, Barik, and Dubey (2018); 24-Abdellatif, Mohamed, et al. (2019); 25-Abdellatif, Emam, et al. (2019); 26-Xie et al. (2018); 27-Pardede (2018); 28-Zhang, Qiu, et al. (2017); 29-Dautov, Distefano, and Buyya (2019); 30-Amato et al. (2019); 31-Onasanya, Lakkis, and Elshakankiri (2019); 32-Singh et al. (2018); 33-Khan et al. (2019); 34-Baker, Xiang, and Atkinson (2017); 35-Alhamid (2017); 36-Yang et al. (2018); 37-Chen et al. (2016); 38-Kang et al. (2018); 39-Stevenson (2011); 40-Chen and Chang (2013); 41-Onasanya and Elshakankiri (2019); 42-Kim, Jeong, and Park (2016); 43-Shi et al. (2016); 44-Wan et al. (2018).

Table 2. Most frequently cited contributions and benefits from the incorporation of ICTs in healthcare systems.

| Authors | $c_1$-Cost reduction | $c_2$-Wireless sensor networks for improved transparency | $c_3$-Electronic health record systems | $c_4$-Usage of mobile health applications | $c_5$-Improve diagnosis and patient care practices | $c_6$-Support of personalised medicine prospects | $c_7$-Lower waiting/ lead times | $c_8$-Foster collaborative healthcare | $c_9$-Improved support to training and education |
|---|---|---|---|---|---|---|---|---|---|
| Jeong, Han, and You (2016) | | √ | √ | √ | √ | | √ | √ | |
| Garai et al. (2017) | | | √ | √ | | √ | | | |
| Ali et al. (2018) | √ | √ | √ | | √ | √ | √ | | |
| Sannino, De Falco, and De Pietro (2019) | | √ | √ | √ | √ | √ | | | |
| Wang, Kung, and Byrd (2018) | √ | | √ | | | | √ | √ | |
| Elhoseny et al. (2018) | √ | | √ | √ | √ | | √ | √ | |
| Aceto, Persico, and Pescapé (2018) | √ | √ | √ | √ | √ | √ | | | |
| Manogaran et al. (2018) | | √ | √ | √ | √ | √ | √ | | |
| Wang, Kung, Wang, et al. (2018) | | √ | √ | √ | √ | √ | √ | √ | |
| Almulhim, Islam, and Zaman (2019) | | √ | √ | √ | √ | √ | | | |
| Demirkan (2013) | √ | √ | √ | √ | √ | √ | √ | √ | |
| Yang et al. (2015) | √ | √ | √ | | √ | | | √ | |
| Peng et al. (2017) | | √ | √ | √ | √ | √ | | | |
| Pace et al. (2019) | | √ | √ | √ | √ | √ | √ | √ | |
| Hassan et al. (2019) | | √ | √ | √ | √ | √ | | | |
| Rajan and Rajan (2018) | | √ | √ | √ | | | | | |
| Catarinucci et al. (2015) | | √ | √ | √ | √ | √ | √ | √ | |
| Yang et al. (2016) | | √ | √ | √ | √ | | | | |
| Munzer et al. (2019) | √ | | | | | √ | √ | | √ |
| Alhussein et al. (2018) | | | √ | √ | | √ | | | |
| Amin et al. (2019) | | √ | √ | √ | | √ | | | |
| Chen et al. (2018) | √ | √ | √ | √ | √ | | | | |
| Abdellatif, Mohamed, et al. (2019) | | √ | | √ | √ | √ | | √ | |
| Guha and Kumar (2018) | | √ | √ | √ | √ | √ | | √ | √ |
| Mutlag et al. (2019) | | √ | √ | √ | √ | √ | | | |
| Mahmoud et al. (2018) | | √ | √ | √ | √ | √ | √ | √ | √ |
| Qi et al. (2018) | | √ | √ | √ | √ | √ | √ | | √ |
| Pan et al. (2018) | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| Xie et al. (2018) | | √ | √ | √ | √ | √ | √ | √ | √ |
| Amato et al. (2019) | √ | √ | √ | √ | √ | √ | | | |
| Onasanya, Lakkis, and Elshakankiri (2019) | | √ | √ | √ | √ | √ | √ | √ | |
| Khan et al. (2019) | | √ | √ | √ | √ | √ | | | |
| Baker, Xiang, and Atkinson (2017) | | √ | √ | √ | √ | √ | √ | | |
| Albesher (2019) | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| Kim, Jeong, and Park (2016) | | √ | √ | √ | √ | √ | | | |
| Sakr and Elgammal (2016) | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| Hsu and Li (2019) | | √ | √ | √ | √ | √ | | | |
| Yuehong et al. (2016) | | √ | √ | √ | √ | √ | | √ | √ |
| Onasanya and Elshakankiri (2019) | √ | | | | √ | √ | | √ | |
| Yang et al. (2018) | √ | √ | √ | √ | √ | √ | √ | | |
| Kang et al. (2018) | | √ | √ | √ | √ | √ | | | |
| Chen et al. (2016) | √ | | | X | X | X | √ | √ | √ |
| Total frequency | 15 | 35 | 38 | 37 | 36 | 35 | 20 | 19 | 10 |

We were also able to list eight barriers and challenges for a successful H4.0 adoption, which are given in Table 3. From those, poor ICT infrastructure ($b_2$) and information security risks ($b_6$) are the most predominant in the literature. Pan et al. (2018) emphasise that the adoption of novel ICTs may also find resistance from physicians, who view automatised medical decision systems as replacers of their expertise. Besides the frequency variation, the nature of the barriers identified in our study nature may also differ from purely technical difficulties to social and organisational challenges. Social barriers concern the emotional or intangible aspects that may impair H4.0 implementation, such as misalignment with hospital's strategy, poor knowledge about technologies, absence of a qualified team and difficulties in finding good partners. Technical barriers refer to tangible or logical components that are considered critical in H4.0 implementation, such as information security risks, implementing costs, regulatory changes and incorporated IT infrastructure. In this sense, Gastaldi and Corso (2012) emphasised that additional barriers may emerge if hospitals do not prepare the required technical and social changes to support a successful H4.0 adoption. The adoption of H4.0 technologies implies the organisational development of not one, but a set of routines. As the number of routines increases, implementation becomes more challenging since developing routines in face of technological changes (i.e. higher-level organisational routines) requires dynamic capabilities (Schilke 2014).

Table 3. Most frequently cited barriers and challenges for the incorporation of ICTs in healthcare systems.

| Authors | $b_1$-Regulatory changes | $b_2$-Poor ICT infrastructure | $b_3$-Misalignment between ICT adoption and organisation strategy | $b_4$-Patents, price ceilings and lack of partnerships | $b_5$-Lack of ICTs' skills | $b_6$-Information security risks | $b_7$-Implementation costs | $b_8$-Devices/systems heterogeneity |
|---|---|---|---|---|---|---|---|---|
| Almulhim, Islam, and Zaman (2019) | | | √ | | | √ | | |
| Elhoseny et al. (2018) | | √ | | | | | | |
| Ali et al. (2018) | √ | √ | | √ | √ | √ | √ | |
| Sannino, De Falco, and De Pietro (2019) | | | √ | √ | | √ | | |
| Garai et al. (2017) | | √ | | √ | | √ | | |
| Jeong, Han, and You (2016) | | | √ | | | √ | √ | |
| Hamidi (2019) | √ | √ | √ | √ | | | √ | |
| Manogaran et al. (2018) | | | | | √ | √ | | |
| Wu et al. (2018) | | √ | √ | | | √ | | |
| Demirkan (2013) | | √ | | | √ | √ | √ | |
| Wang, Lu, et al. (2019) | | √ | √ | | √ | √ | √ | |
| Peng et al. (2017) | | √ | | √ | √ | √ | | |
| Wang, Kung, Wang, et al. (2018) | | √ | √ | √ | √ | √ | | |
| Pace et al. (2019) | | √ | | √ | √ | √ | √ | |
| Rajan and Rajan (2018) | | √ | | | | √ | | |
| Catarinucci et al. (2015) | | √ | √ | | | √ | | |
| Munzer et al. (2019) | | √ | | √ | √ | | √ | |
| Rghioui and Oumnad (2018) | | √ | | √ | √ | √ | √ | |
| Kim and Choi (2016) | √ | √ | | √ | √ | √ | √ | |
| Kim (2015) | | | | √ | | | | |
| Saxena and Raychoudhury (2017) | √ | √ | | √ | √ | √ | | √ |
| Abdellatif, Mohamed, et al. (2019) | | | √ | | | √ | | √ |
| Guha and Kumar (2018) | | √ | | | | √ | √ | √ |
| Mutlag et al. (2019) | | √ | | | √ | √ | | √ |
| Mahmoud et al. (2018) | √ | √ | √ | | | √ | √ | |
| Gomez-Sacristan, Rodriguez-Hernandez, and Sempere (2015) | | √ | | | | | √ | √ |
| Pan et al. (2018) | | √ | √ | √ | √ | | √ | |
| Kumari et al. (2018) | √ | √ | √ | √ | √ | √ | √ | √ |
| Kharel, Reda, and Shin (2019) | | √ | | | √ | √ | | √ |
| Zhang, Qiu, et al. (2017) | √ | √ | | √ | √ | √ | √ | √ |
| Singh et al. (2018) | | | | √ | √ | √ | √ | |
| Palanisamy and Thirunavukarasu (2017) | | √ | √ | | | √ | | |
| Baker, Xiang, and Atkinson (2017) | | √ | | √ | | √ | | √ |
| Albesher (2019) | | √ | | √ | √ | √ | √ | √ |
| Sawa (2011) | √ | √ | √ | √ | √ | | √ | |
| Stevenson (2011) | √ | √ | √ | √ | √ | √ | √ | √ |
| Sakr and Elgammal (2016) | | √ | √ | √ | √ | √ | √ | |
| Aceto, Persico, and Pescapé (2018) | √ | √ | √ | √ | √ | √ | √ | √ |
| Hsu and Li (2019) | √ | √ | | | √ | √ | √ | |
| Din and Paul (2019) | | √ | | √ | | | √ | |
| Gastaldi and Corso (2012) | √ | √ | √ | √ | √ | | √ | √ |
| Onasanya and Elshakankiri (2019) | | | √ | √ | | √ | | |
| Total frequency | 12 | 34 | 19 | 25 | 24 | 33 | 24 | 13 |

## 5. H4.0 implementation trends

According to Anand and Kodali (2010), organisations that aim at achieving superior performance by implementing new management principles and techniques such as H4.0 may need some guidance towards more assertive decisions and efforts (Jasti and Kodali 2014). To provide such guidance we identified trends in H4.0 implementation mostly related to the integration of modern ICTs into healthcare systems aimed at improving their value streams. Nine ICTs listed in Table 1 were qualitatively and quantitatively analysed based on two dimensions: (*i*) their role within healthcare organisations (qualitative analysis), and (*ii*) their application in hospitals' value streams (quantitative analysis).

Regarding the role of ICTs in healthcare organisations, Aceto, Persico, and Pescapé (2018) proposed four interrelated subsets of ICTs: (*i*) communication, (*ii*) sensing, (*iii*) processing, and (*iv*) actuation. Communication involves different forms of interaction and dissemination of health-related information, supporting patient-professional relationships and collaborative care. In this sense, H4.0 technologies provide support to increase accessibility, exchange, and sharing of information. Sensing refers to the acquisition of information about a patient, equipment, material or process without necessarily making physical contact with them. Processing denotes ICTs that may change or process the acquired data producing actual information in any manner detectable by an observer. Finally, actuation refers to ICTs responsible for moving and controlling a system, mechanism (electronic or mechanical) or software based on the information and signals received. There may be overlaps between those subsets; i.e. ICTs may be categorised in more than one subset depending on the extent of the role they play within the healthcare system. Therefore, each ICT was subjectively scored according to the pertinence to the four subsets above as reported in the literature analysed, with values ranging from 3 (strong pertinence) to 1 (weak pertinence). In other words, when a certain ICT had multiple references in the portfolio explicitly evidencing its usage for that role, we scored as 'strong pertinence'. If no evidence was found for the ICT playing that role, we assigned as 'weak pertinence'. 'Medium pertinence' was assigned to the ICTs whose evidence on a certain role was implicit and not quite clear in the studies. It is worth mentioning that this qualitative analysis was independently conducted by two of the researchers, who had their scores and arguments conciliated by a third researcher. This conciliation allowed to establish consensus and consistency on the reasoning for the assigned scores. The final pervasiveness score of a given ICT was defined as the sum of their respective scores for each subset; final values were rescaled onto a [0, 1] continuous scale. Results are shown in the left portion of Table 4.

To analyse the application of ICTs in hospitals' value streams, we checked for the most common types of flow cited in the literature. Patients flow encompasses the systematic process of attending to patients, from the time they walk into a hospital or medical facility to the time they check out for discharge, including both medical and administrative functions (Kumar, Swanson, and Tran 2009). It is also known the existence of other flows, such as medical consumables (Jahre et al. 2012), information (Teichgräber and De Bucourt 2012), process or work operation flow (McGough, Kline, and Simpson 2017), which may include goods, materials, equipment, medicines, information, among others. Thus, we adopted the classification proposed by Borges et al. (2019), comprised of seven main streams (or flows): patients, materials, processes, medicines, consumables, information and equipment. ICTs had their respective citation frequency determined according to the value streams in which they were reportedly applied in the literature analysed. Three frequency scores were assigned relating a given ICT to value streams: 3, when more than 50% of studies reported its application (on a given value stream); 2, when 25% to 50% of studies reported its application; and 1, when less than 25% of studies reported its application. The final value stream score for a given ICT was obtained summing its frequency scores overall streams and rescaling the result onto a [0, 1] continuous scale. Results are shown in the right portion of Table 4.

Table 4. Proposed framework for H4.0 implementation.

| ICT | Role[a] | | | | Role pervasiveness score | | Hospital's value stream[b] | | | | | | | Value stream score | | Importance score[c] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Communication | Sensing | Processing | Actuation | Total | Rescaled [0–1] | Patients flow | Materials flow | Processes flow | Medicines flow | Consumables flow | Information flow | Equipment flow | Total | Rescaled [0–1] | Total | Diff. Index |
| Biomedical/digital wireless sensor | 2 | 3 | 1 | 1 | 7 | 0.123 | 2 | 1 | 2 | 1 | 1 | 3 | 1 | 11 | 0.103 | 0.013 | 0.057 |
| IoT | 3 | 2 | 2 | 1 | 8 | 0.140 | 3 | 2 | 1 | 2 | 2 | 3 | 2 | 15 | 0.140 | 0.020 | **2.270** |
| Machine/Deep learning | 1 | 1 | 3 | 1 | 6 | 0.105 | 2 | 1 | 2 | 1 | 2 | 3 | 1 | 12 | 0.112 | 0.012 | −0.200 |
| Big data | 1 | 1 | 3 | 1 | 6 | 0.105 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 14 | 0.131 | 0.014 | 0.417 |
| Cloud/Fog computing | 2 | 1 | 2 | 1 | 6 | 0.105 | 2 | 3 | 1 | 2 | 2 | 3 | 1 | 14 | 0.131 | 0.014 | 0.417 |
| Augmented reality/simulation | 1 | 1 | 1 | 3 | 6 | 0.105 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 9 | 0.084 | 0.009 | −1.126 |
| Remote control/ monitoring | 3 | 1 | 1 | 1 | 6 | 0.105 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 11 | 0.103 | 0.011 | −0.509 |
| 3D printing | 1 | 1 | 1 | 3 | 6 | 0.105 | 1 | 3 | 2 | 1 | 1 | 2 | 1 | 11 | 0.103 | 0.011 | −0.509 |
| Collaborative robots/robotics | 1 | 1 | 1 | 3 | 6 | 0.105 | 1 | 1 | 3 | 1 | 1 | 1 | 2 | 10 | 0.093 | 0.010 | −0.818 |
| Total | 15 | 12 | 15 | 15 | – | – | 16 | 16 | 15 | 13 | 12 | 21 | 11 | – | – | | |

[a]Evidenced emphasis: 1 = Low; 2 = Moderate; 3 = High.
[b]Citation frequency: 1 = Low (less than 25%); 2 = Medium (between 25% and 50%); 3 = High (more than 50%).
[c]Obtained multiplying pervasiveness and value stream rescaled scores.

Pervasiveness and value stream scores for each ICT were then multiplied to obtain a final ICT importance score. A high importance score indicates versatile ICTs both in terms of role within the healthcare system and value stream application. To compare and rank ICTs regarding their importance in H4.0 implementation, we established an index given by the number of standard deviations each individual ICT score displays with respect to the overall average score. A similar differentiation index was used in previous studies (e.g. Tortorella and Fogliatto 2014; Tortorella, Vergara, et al. 2017) to remove scale effects and indicate managerial priorities for implementation.

Results displayed in Table 4 show that IoT (diff. index = 2.270) have a distinguished role and applicability in healthcare systems. IoT extends Internet connectivity to physical devices and objects, allowing the communication and interaction with others, and enabling remote monitoring and control (Alhamid 2017; Onasanya and Elshakankiri 2019). This ICT plays a key role in interconnecting patients, healthcare professionals, equipment, materials and hospital management so that information is shared, supporting more assertive decisions. Our findings reinforce such concept stressing IoT's high pervasiveness and integration capacity, both horizontally and vertically within a hospital. Given the interdisciplinary and complex nature of most healthcare systems, IoT should be prioritised in hospitals aiming at H4.0 implementation.

The ICT with lowest important score is 'augmented reality/simulation'. It aims at providing an interactive experience of a real-world environment where situations/objects are enhanced by computer-generated perceptual information through multiple sensory modalities (e.g. visual, auditory, haptic, somatosensory and olfactory) (Barfield 2015). Its application in healthcare systems is more frequently reported in surgical procedures, with the main objective of educating and training medical staff (Dautov, Distefano, and Buyya 2019; Munzer et al. 2019). Due to such narrow applicability the implementation of this ICT should not be viewed as a priority, particularly in resource-constrained environments.

From Table 4, we observe a well-balanced emphasis of H4.0 implementation across the four subsets in terms of the roles played by each ICT. However, a stronger emphasis on sensing is present in studies reporting the use of 'biomedical/digital wireless sensor'. As this ICT fundamentally works as a means to acquire data either from patients, materials or equipment (Kim, Jeong, and Park 2016; Wan et al. 2018), its significant contribution to this subset may be expected.

Regarding value streams, H4.0 implementation is more commonly found in hospitals' information flows, comprised of all procedures, analyses, decisions and orders needed to support processes and health services in a sequential way, according to patients/customers' expectations (Womack et al. 2005; Tortorella, Fogliatto, et al. 2017). The majority of studies that report H4.0 applications in information flows are related to healthcare treatments (see Table 1). Such studies (e.g. Demirkan 2013; Catarinucci et al. 2015) aimed at improving information flow through the adoption of H4.0 so that the performance of specific health treatments could be enhanced, corroborating our findings.

Overall, Table 4 indicates the most important ICTs to be considered in an H4.0 implementation. That may serve as guideline to healthcare organisations regarding the sequence in which ICTs should be considered for implementation, leading to more assertive managerial efforts and decisions. We understand that this is a key outcome from Table 4 and helps to answer *RQ2*.

## 6. Research agenda

Based on the results observed in sections 4 and 5 of our study, we identified gaps related to H4.0 adoption that should be addressed towards a more holistic integration of ICTs in healthcare system and achievement of expected benefits. We organised those gaps in three main directions for future research, which are presented next.

### *6.1. Systematic integration of H4.0 elements in healthcare organisations*

Healthcare organisations are complex systems comprised of different departments (e.g. emergency department and operating theatre) that demand resources, in terms of infrastructure and information, that are frequently shared (Dautov, Distefano, and Buyya 2019). Therefore, the adoption of ICTs by a given department should be analysed considering the benefits of its implementation both locally and systemically. For example, ICTs that enable the online monitoring of patients' vital signals are relevant to professionals directly providing care, but also to operating theatre managers scheduling procedures for the next day and considering certain patients as candidates.

None of the 78 articles examined in this scoping study reporting the adoption H4.0 used a systemic approach that considered information sharing across different hospital processes. In fact, all implementation initiatives had very specific focuses, usually targeting at certain healthcare treatments or administrative processes. Such narrow perspective should yield local process improvements that do not operate in a synergic manner.

There is need for developing a generalisable and patient-oriented approach that provides managers guidelines to properly integrate H4.0 adoption across all hospital processes, treatments, departments, stakeholders and partners (e.g. health insurers and regulatory agencies). Future studies aiming at such systemic integration of H4.0 could benefit from analysing well-succeeded experiences from the process reengineering movement (such as those reported by O'Neill and Sohal 1999), since both initiatives share similar characteristics. Further, H4.0 roadmaps could be proposed as means to support such systemic implementation approaches. This would enable the establishment of clear and more specific directions for healthcare organisations to start their digital transformation.

### 6.2. Influence of contingency factors on H4.0 adoption

The understanding of healthcare systems' contingencies is fundamental for an assertive H4.0 adoption and deserves further attention from researchers. According to contingency theory (Sousa and Voss 2008), organisations should not indistinctly adopt the same set of techniques or tools since adoption is conditioned to characteristics that vary from one system to another (Boer et al. 2017). Being a technology-driven movement, high levels of capital expenditure and workforce skills are some of the factors that may determine a successful implementation of H4.0 (Thuemmler and Bai 2017). Thus, contextual factors such as socioeconomic development of the region/country and hospital's type (public or private) may directly impact on a hospital's capability to extensively implement H4.0.

Authors that investigated the effect of contingencies on H4.0 implementation focussed on a limited number of variables. Albesher (2019) stated that the use of ICTs in healthcare systems ranged from pilot projects to full-scale implementations in countries such as Japan, France and Sweden. Differences in background were responsible for high variation in terms of used approaches and achieved results, reinforcing the need to better understand the effect of contingencies on H4.0 implementation. Few studies (e.g. Moores 2012; Zhang, Luo, et al. 2017) investigated the moderating effect of certain demographic factors deemed as internal contingencies (e.g. gender and age) on the adoption level of new ICTs in healthcare systems. Pan et al. (2018) explored behavioural intentions towards smart healthcare services among medical technicians and clinicians from the perspective of technology transfer. Their findings confirmed differences in perceptions and behavioural intentions regarding new ICTs' adoption.

Due to the complexity of healthcare systems, contingency analysis should encompass those external to the hospital (e.g. socioeconomic context of the region/country) as well as internal contingencies, such as type of management, hospital size, differences in processes and departments, and staff educational level. We pose that future studies on H4.0 adoption should examine contingencies identifying their source (internal or external) and type (e.g. related to individual background or regional characteristics), predicting their effects on H4.0 implementation and proposing ways to benefit from them. Additionally, these studies could check for the necessary adaptations in the H4.0 implementation throughout different contexts. This would help the establishment of comparative parameters for H4.0 implementation among healthcare organisations with similar contingencies.

### 6.3. Managing sociocultural factors to support H4.0

H4.0 is viewed as a derivation of I4.0 whose main design principles are interconnection, information transparency, technical assistance and decentralised decisions (Hermann, Pentek, and Otto 2016). Adherence to those principles supported by proper ICTs may lead to significant changes in the way healthcare systems operate. Hua (2007) states that organisational changes such as the one derived from H4.0 adoption should be grounded on technical and sociocultural factors: while the former represent logical or tangible components that are critical for performance improvement (e.g. ICTs), the latter relates to emotional or intangible components that are usually neglected, but also relevant for a successful organisational change. In fact, sociocultural factors are deemed responsible for building behaviours and mindsets that support and sustain changes in the long term (Tortorella and Fogliatto 2014).

The majority of studies examined in our review are technical-oriented and disregard sociocultural factors. As H4.0 implementation may entail a reorganisation of hospitals based on I4.0 design principles, Alloghani et al. (2018) emphasised that healthcare organisations should move from a technology-centered to a patient-centered approach, leading to changes in organisational structures, strategies and culture. Technology should adapt to patients' and caretakers' beliefs and constraints to effectively promote systemic benefits, and that could only be attained by carefully analysing the sociocultural characteristics of the environment in which the healthcare system operates. In other words, H4.0 implementation should consider the values and behaviours of the involved agents (patients, families, caretakers, organisations, etc.) so that the integration of digital technologies corroborate with their expected benefits mitigating conflicts.

Further research on H4.0 should explore intrinsic sociocultural factors of healthcare organisations and their value chain, adapting technology to actors in search of better and more permanent results. Working on sociocultural factors tend to be more time-consuming than on technical factors, requiring early measures to adapt organisations to an H4.0 implementation. Hence, studies could provide managers arguments to anticipate sociocultural factors that may act as promoters of change and define strategies to lapidate them looking for an effective transformation of the healthcare system towards the fourth industrial revolution era. A clear understanding of sociocultural factors may increase the effectiveness of technical factors and boost managerial efforts.

## 7. Conclusions

This research examined how the implementation of H4.0 is being approached in healthcare systems based on a scoping review of the literature. For that, we searched journal articles in four databases and screened relevant articles to consolidate a publications' portfolio on the topic, following predefined criteria. Results of the scoping review were explored through: (*i*) a descriptive numerical summary and thematic analysis; (*ii*) identification of trends in H4.0 implementation; and (*iii*) identification of theoretical gaps and proposition of future research directions from a healthcare operations management point of view. We observed that, despite the recency of the subject, research in H4.0 has been conducted in an interdisciplinary way with a diversified set of applications and functionalities. In terms of its implementation, H4.0 has been more commonly found in hospitals' information flows, especially the ones related to healthcare treatments. The identified implementation trends, however, neglect a more holistic approach for H4.0, which originated three main research directions for this topic.

A few limitations in our study are noteworthy, mostly related to its nature and methodological choices. Since I4.0 has been formally acknowledged in 2011 and H4.0 is a concept derived from it, our scoping study only encompassed publications after that year. However, it is worth mentioning the existence of initiatives aimed at integrating ICTs in healthcare systems dating earlier than 2011 (e.g. Kim and Min 2004; Alemdar and Ersoy 2010), and that is a limitation in our research. Nevertheless, as studies prior to 2011 were scarce and scattered, and the number of publications in the topic has significantly increased in the past few years (as shown in Figure 1), we believe that our choice of search period returned all relevant works on H4.0. A second limitation is that we focussed our literature analysis and discussion on H4.0 implementation within hospitals. However, the concept of healthcare has expanded and gone beyond the limits of healthcare organisations (i.e. hospitals and clinics). In fact, with the advent of 'smart cities', complementary aspects of healthcare have been integrated due to the increased level of interconnectivity and data acquisition, allowing to remotely demand healthcare services. Our study did not analyse those aspects and exclusively considered hospitals as units of analysis. Finally, the proposition of a roadmap for H4.0 implementation was not comprised in our objectives. The identification of trends, challenges and theoretical gaps through this scoping review was a first step towards the proposition of such roadmap, allowing an initial mapping and consolidation of the body of knowledge on H4.0. Therefore, further studies could use the theoretical consolidation of the literature performed in our study as a conceptual subside for developing a H4.0 implementation roadmap.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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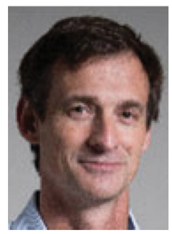

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