UNLOCKING HEALTHCARE 4.0: NAVIGATING CRITICAL SUCCESS FACTORS FOR EFFECTIVE INTEGRATION IN HEALTH SYSTEMS

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ABSTRACT

The Fourth Industrial Revolution is transforming industries, including healthcare, by integrating digital, physical, and biological technologies. This study examines the integration of 4.0 technologies into healthcare, identifying success factors and challenges through interviews with 70 stakeholders from 33 countries. Healthcare is evolving significantly, with varied objectives across nations aiming to improve population health. The study explores stakeholders' perceptions on critical success factors, identifying challenges such as insufficiently trained personnel, organizational silos, and structural barriers to data exchange. Facilitators for integration include cost reduction initiatives and interoperability policies. Technologies like IoT, Big Data, AI, Machine Learning, and robotics enhance diagnostics, treatment precision, and real-time monitoring, reducing errors and optimizing resource utilization. Automation improves employee satisfaction and patient care, while Blockchain and telemedicine drive cost reductions. Successful integration requires skilled professionals and supportive policies, promising efficient resource use, lower error rates, and accelerated processes, leading to optimized global healthcare outcomes.

KEYWORDS

Fourth Industrial Revolution, Healthcare 4.0, Health Systems, Health Innovations, Healthcare Management

1. INTRODUCTION

Currently, we are experiencing the Fourth Industrial Revolution (4IR), also referred to as Industry 4.0. This revolution stands apart from all previous Industrial Revolutions by merging the digital, physical, and biological realms, leading to systemic transformations across governments, businesses, industries, and society through emerging technologies [1]. One of the sectors impacted is the healthcare sector, as it is exposed to technological evolution, being affected by digitization, revolutionizing the entire way healthcare is delivered, from the interaction between patients and healthcare providers to governments and stakeholders [1].

Through 4.0 technologies, changes are occurring in the organization and structure of healthcare systems. It is important to understand them as they enable new methods of treatment, diagnosis, and monitoring of patients' health status, changes in the management of healthcare institutions, and the way healthcare is accessed [2].

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There is no consensus in the literature for a definition of healthcare systems; these are a cluster of complex elements that interact together to form an even more complex system, whose interactions affect the achievement of health system objectives, regardless of these objectives varying between countries, in essence, they are similar, as the objective of any healthcare system is to improve the health of the population [3].

The main objective of the present study focused on understanding the perception of a set of qualified stakeholders regarding the critical success factors for the effective integration of healthcare 4.0 in health systems.

2. Materials and Methods

The main objective of this study was to understand the perception of a group of qualified individuals regarding the critical success factors for the successful implementation of healthcare 4.0 in health systems. We established the following specific objectives: to identify difficulties in the process of implementing 4.0 technologies in health systems; to identify factors that facilitate the introduction of 4.0 technologies in healthcare systems; to understand the interviewees' perception of the effect of 4.0 technologies on the effectiveness of healthcare systems; to understand the interviewees' perception of the effect of 4.0 technologies on the efficiency of healthcare systems.

We opted for an exploratory descriptive study with a qualitative approach, and semi-structured interviews were conducted with 70 national and international personalities and stakeholders in the healthcare sector from 33 different countries, covering all 7 continents, including healthcare professionals in leadership positions and managers. The interview guide was based on the specific objectives of the study. The interviews took place from March 27, 2020, to November 2, 2020.

Table 1. Specific objectives of the study and questions included in the interview guide. Source: Own elaboration.

Specific objectives	**Interview guide questions**
Identify difficulties in the process of implementing 4.0 technologies in health systems	What are the main difficulties resulting from the implementation of technologies stemming from Industry 4.0 in healthcare systems?
Identify factors that facilitate the introduction of 4.0 technologies in healthcare systems	What are the facilitating factors in the introduction of technologies stemming from Industry 4.0 in healthcare systems?
Understand the interviewees' perception of the effect of 4.0 technologies on the effectiveness of healthcare systems	In your opinion, what is the effect of the Fourth Industrial Revolution on the effectiveness of healthcare systems?
Understand the interviewees' perception of the effect of 4.0 technologies on the efficiency of healthcare systems	In your opinion, what is the effect of the Fourth Industrial Revolution on the efficiency of healthcare systems?

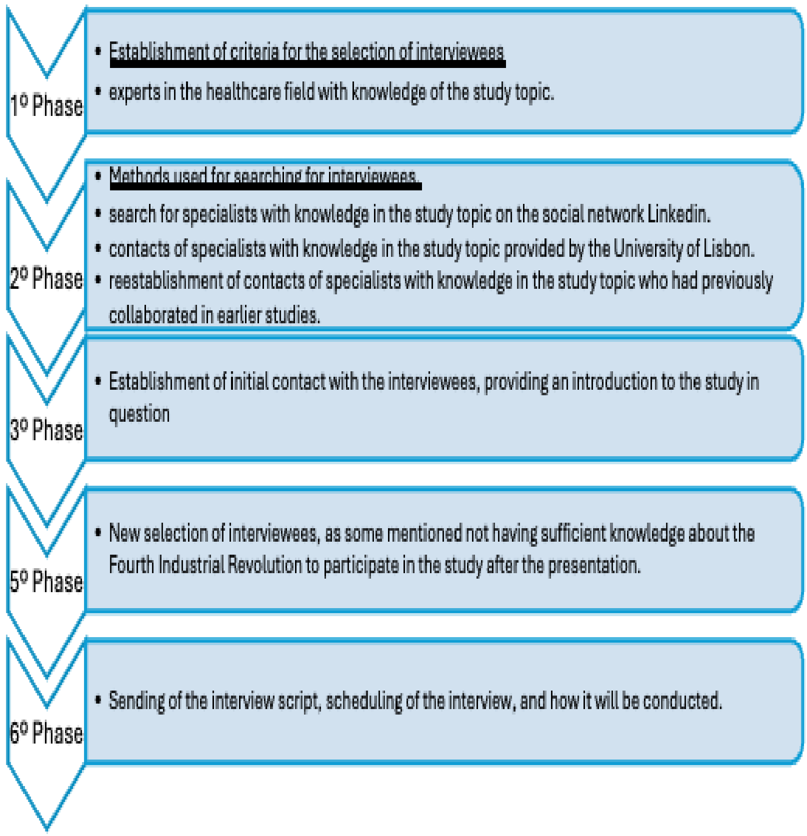

Figure 1. Framework for finding interviewees for the study. Source: Own elaboration.

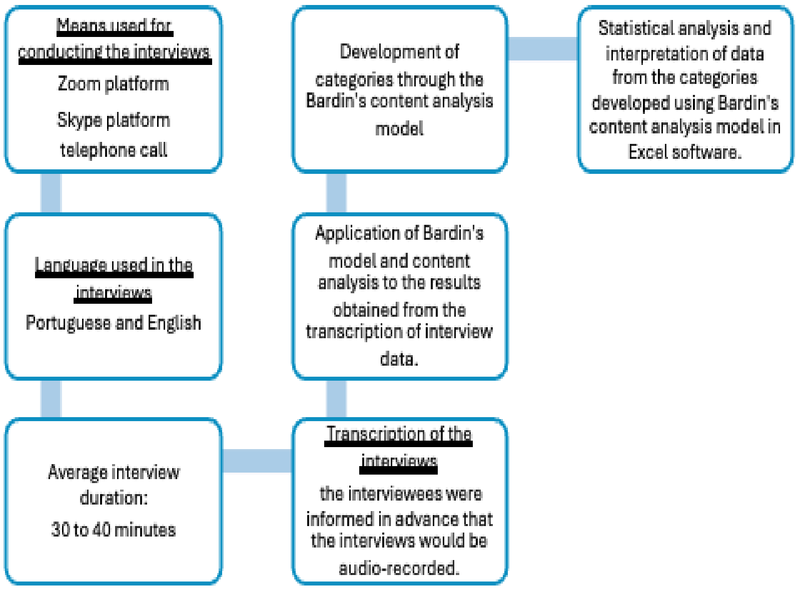

Figure 2. Framework for conducting interviews and data processing. Source: Own elaboration.

Table 2. List of countries of the interviewees. Source: Own elaboration.

Countries	**Number of interviewees**
Argentina	2
Australia	1
Belgium	2
Brazil	8
Cuba	3
Denmark	2
Dubai	2
England	3
Germany	1
Greece	1
Guatemala	1
Haiti	2
India	1
Israel	1
Italy	3
Japan	2
Kenya	2
Mexico	2
Netherlands	1
New Zealand	1
Nigeria	2
Peru	1
Philippines	1
Portugal	4
Russia	2
Serbia	2
Singapore	2
Slovenia	1
Spain	3
Switzerland	1
Thailand	1
United Arab Emirates	3
United States of America	7

3. RESULTS

Through the content analysis methodology from Bardin's perspective, categories were created for each of the questions in the script representing the respondents' perceptions, where the percentage values obtained are cumulative, as in some questions, the interviewees responded to multiple categories simultaneously.

Table 3. Presentation of the results, associating the questions with the generated categories and their respective percentages. Source: own elaboration

Question	Category	Percentage (%)
(1) What are the main difficulties resulting from the implementation of technologies stemming from Industry 4.0 in healthcare systems?	Lack of qualified human resources	40%
(1) What are the main difficulties resulting from the implementation of technologies stemming from Industry 4.0 in healthcare systems?	Structure of healthcare systems	50%
(2) What are the facilitating factors in the introduction of technologies stemming from Industry 4.0 in healthcare systems?	Cost reduction	41,4%
(2) What are the facilitating factors in the introduction of technologies stemming from Industry 4.0 in healthcare systems?	Interoperability policies in healthcare systems	64,3%
(3) In your opinion, what is the effect of the Fourth Industrial Revolution on the effectiveness of healthcare systems?	Better management outcomes	64%
(3) In your opinion, what is the effect of the Fourth Industrial Revolution on the effectiveness of healthcare systems?	Improved healthcare delivery outcomes	74%
(4) In your opinion, what is the effect of the Fourth Industrial Revolution on the efficiency of healthcare systems?	Maximization of human and financial resources utilization	80%
(4) In your opinion, what is the effect of the Fourth Industrial Revolution on the efficiency of healthcare systems?	Reduction in the time consumed by healthcare system processes	67,1 %
(4) In your opinion, what is the effect of the Fourth Industrial Revolution on the efficiency of healthcare systems?	Lower error rates	42,8%

Addressing the complexities surrounding the integration of 4IR technologies in healthcare systems requires understanding the encountered barriers. Through interviews with key stakeholders, a notable challenge emerged: the lack of adequately trained human resources. This deficiency impedes the seamless incorporation of 4.0 technologies throughout the healthcare continuum. The absence of requisite training programs inhibits the effective utilization of these advanced technologies, emphasizing the need for healthcare professionals to possess the necessary education and training to leverage 4.0 technologies optimally. Furthermore, organizational structures within health systems present barriers to the widespread adoption of 4IR innovations. Functional silos within healthcare institutions complicate the cohesive implementation of new technologies. Interviewees highlighted the discordant digital ecosystems across healthcare organizations, which misalign with the overarching digital culture of the 4.0 era. This misalignment hinders the harmonized integration of innovative technologies, underscoring the need for alignment and collaboration to overcome these structural challenges.

In response to question 2, interviewees highlighted the key role of 4IR technologies in reducing costs within healthcare systems. Despite initial investment hurdles, these innovations optimize various processes. Technologies like the Internet of Things (IoT) and Big Data (BD) streamline information sharing and communication among healthcare organizations. Data Analysis (DA) and Data Science (DS) automate administrative analyses, yielding substantial cost savings and preserving human capital for higher-value tasks. Artificial Intelligence (AI), Machine Learning (ML), and Precision Medicine (PM) expedite diagnoses and treatments, reducing clinical process costs. Nanotechnology, 3D printing, and robotics minimize invasiveness in clinical interventions, cutting costs and recovery times, leading to fewer hospitalizations. Continuous data collection from sensors and wearables supports remote and home-based care, decreasing hospitalizations and response times, enhancing cost efficiency. Interviewees underscored the role of interoperability policies in facilitating 4.0 technology implementation in healthcare systems. These policies eliminate bureaucratic barriers, enabling safer and faster data exchange among organizations, improving management and communication. Overall, interviewees emphasized that 4.0 technologies establish interoperable infrastructures across regional, national, and international domains. These advancements alleviate pressures from top-down regulations, horizontal peer collaboration, and bottom-up demands for best practices and professional development. By addressing these challenges, 4.0 technologies are set to drive cost efficiency and interoperability, transforming global healthcare delivery.

In response to question 3, interviewees affirmed that the 4IR is driving superior management outcomes in health systems. They highlighted how 4.0 technologies enhance communication and info exchange among diverse healthcare organizations. Platforms like IoT, BD, and Cloud Computing (CC) facilitate rapid info sharing, fostering agility and reducing operational distances, leading to more precise management, improved organization, and enhanced analysis and monitoring of info, aiding decision-making and management processes. AI particularly contributes to optimizing decision-making processes by providing objective insights. Moreover, 4.0 technologies play a pivotal role in strategic management by integrating people management and aligning them with health system goals, increasing transparency. Interviewees observed that the 4IR is reshaping the entire business model associated with healthcare system management, fostering new forms of engagement between suppliers and stakeholders. Additionally, interviewees underscored the positive impact of the 4IR on healthcare delivery outcomes. Technologies such as AI and ML enable more accurate and personalized diagnoses, leading to innovative forms of treatment. Precision Medicine leverages genetic knowledge and sequencing, along with nanotechnology, for early diagnosis and intervention. BD and DA facilitate the comparison of large datasets, leading to more effective clinical interventions. 4.0 technologies enhance patient monitoring within healthcare institutions and remotely, using wearables, IoT, and CC to enable more efficient healthcare provision. Improved healthcare delivery outcomes are also evident in clinical interventions, where robotics and 3D printing enable personalized and less invasive procedures, enhancing patient care and outcomes.

In response to question 4, interviewees emphasized that the 4IR maximizes the utilization of human and financial resources within healthcare systems. At the management level and among healthcare professionals, 4.0 technologies empower individuals with info and automate tasks, enhancing effectiveness in both management and healthcare provision. These technologies drive cost reduction by streamlining info exchange processes through digitization, eliminating paper-based workflows. Centralization of patient data via IoT reduces clinical material waste by enhancing stock management and preventing product expiration. 4.0 technologies facilitate cost-effective healthcare access through telemedicine consults, enabling remote monitoring and reducing hospitalizations. AI, ML, IoT, and wearables support home-based care, maintaining quality while minimizing costs and increasing hospital bed availability. Additionally, 4.0 technologies enable precise and cost-effective treatment and diagnosis, including 3D printing, nanotechnology, and AI-driven diagnostics, revolutionizing traditional healthcare approaches. Interviewees also highlighted how the 4IR contributes to lower error rates in health systems by enabling rapid info exchange and large-scale data analysis, reducing errors in communication between healthcare organizations. Centralization and analysis of clinical data facilitate error reduction in info sharing among providers and patients. AI and ML enhance diagnostic accuracy by analyzing vast datasets, leading to personalized and error-minimized diagnoses. Technologies such as robotics, nanotechnology, and wearables reduce errors in healthcare delivery through precision interventions and real-time alerts to healthcare providers. Overall, 4.0 technologies promote efficiency across healthcare processes by accelerating info exchange through platforms like IoT and CC, enabling rapid access to healthcare services through digital solutions, and facilitating faster treatment and diagnosis through advanced technologies.

4. DISCUSSION

In this section, we address the challenges and facilitating factors associated with implementing Industry 4.0 technologies in healthcare systems. We explore how these technologies impact the effectiveness and efficiency of healthcare delivery and management.

4.1. Challenging Factors

The study identifies challenges in implementing Industry 4.0 technologies in health systems, including a shortage of qualified human resources and inherent structural issues. Despite a plethora of applicable technologies, adoption by healthcare professionals remains slow and inconsistent [4,5]. Addressing these challenges necessitates developing digital literacy among healthcare personnel, ensuring proper training endorsed by professional organizations [6,7], as stressed by Coelho and Jorge (2012) regarding the coupling of high-complexity technologies with professionals' capacity [8].

The structure of health systems poses another obstacle, characterized by functional silos and fragmented communication channels among organizations [9]. This fragmentation leads to systemic misalignment, hindering coordination, resource allocation, and quality of care [10]. Variability and *ad hoc* practices further complicate communication, impeding the implementation of Industry 4.0 technologies [11]. Achieving communication and alignment between organizations is challenging due to incompatible protocols, emphasizing the need for interoperability and eliminating functional silos [12].

4.2. Facilitating Factors

The study underscores several facilitating factors for integrating Industry 4.0 technologies into health systems, including cost reduction initiatives and tailored interoperability policies. These technologies promise to revolutionize healthcare environments, improving outcomes, and significantly cutting costs [12,13]. IoT emerges as a pivotal enabler, facilitating domain-specific applications and enhancing system performance, thus reducing costs associated with information sharing and communication among healthcare organizations [12,13]. Furthermore, the effective integration of data mining and medical informatics, coupled with advanced analytics using BD and DA techniques, promises to drive down healthcare delivery costs while enhancing outcomes [14,15]. The adoption of home hospitalization models, facilitated by Industry 4.0 technologies, offers wireless patient monitoring, data sharing through IoT, and analysis via AI and ML, leading to quicker diagnoses, reduced hospital bed occupancy, and improved patient quality of life [16,17,18].

In health systems, traditional Top-Down hierarchical structures have faced critique for potentially stifling intrinsic motivation and productivity among professionals [19]. Alternatively, Bottom-Up organizational models, proposed by Ellis (2012) and Laloux (2018), offer solutions better tailored to real organizational needs [20,21]. However, transitioning to Bottom-Up models faces challenges within the entrenched Top-Down organizational framework prevalent in health systems [22].

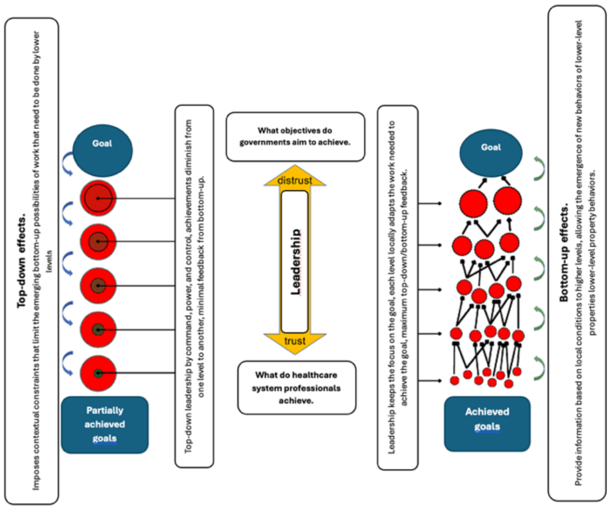

Figure 3. Top-down versus Bottom-up Hierarchy in SDS. Source: Adapted from Sturmberg & Bircher (2019).

Complex Adaptive System (CAS) models, as advocated by Sturmberg (2018), offer a theoretical framework to overcome these constraints, fostering decentralized decision-making and adaptability. CAS models, characterized by hierarchical subsystems and emergent properties, are inherently stable and resilient in fluctuating environments [20,23].

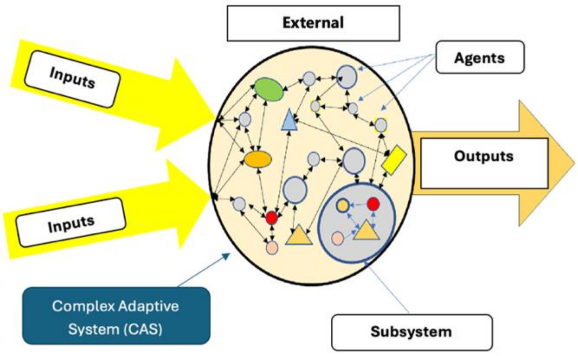

Figure 4. Feedback process in the CAS. Source: Adapted from Sturmberg & Bircher (2019).

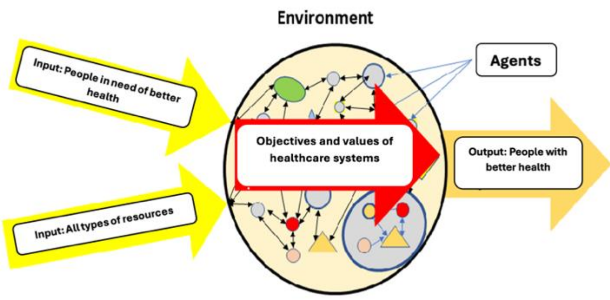

Figure 5. CAS model adapted to SDS: Source: Adapted from Sturmberg & Bircher, (2019).

Industry 4.0 technologies play a vital role in implementing CAS models within health systems by managing data, supporting management processes, and facilitating information exchange among sub-systems [24,25]. These technologies impact CAS models through comprehensive perception, reliable transmission, and intelligent processing [26]. Comprehensive perception involves gathering data using IoT, sensors, and wearables; reliable transmission ensures seamless information sharing via technologies like IoT, Blockchain, and CC; and intelligent processing entails analyzing sensor data using AI and ML [26,27,28]. Thus, Industry 4.0 technologies not only facilitate CAS implementation in health systems but also enable interoperability through standardized data formats, protocols, and types of data among sub-systems and the supersystem [22,29,30].

4.3. Effect on the Effectiveness of Healthcare Systems

The study findings underscore the profound impact of Industry 4.0 technologies on the effectiveness of health systems, spanning improved management and healthcare delivery outcomes. Effectiveness, as defined by Ferreira and Gomes (2009), denotes the alignment between intended goals and achieved results, encapsulating the notion of accomplishing objectives efficiently. In the healthcare context, effectiveness pertains to the capacity for beneficial change resulting from interventions, treatments, or procedures [31,32]. The integration of Industry 4.0 technologies heralds a paradigm shift in health systems, intertwining physical and digital realms to enhance management outcomes [33,34]. By fostering intensive connectivity and data exchange, these technologies optimize resource utilization and streamline processes [35]. Integration and interoperability, essential facets of Industry 4.0, facilitate seamless operations across organizational boundaries, enhancing networked collaboration [36].

Technologies such as AI, ML, and robotics significantly augment healthcare delivery outcomes by enabling more accurate diagnoses and personalized treatments [37,38]. ML algorithms, for instance, enhance survival predictions in conditions like pulmonary hypertension, showcasing their potential to revolutionize patient care [38]. Similarly, AI systems integrated with digital mammography data improve oncology care by identifying patterns undetectable to human observers, thereby reducing false positives and unnecessary procedures [39]. Robotics, exemplified by the Da Vinci surgical system, enhances surgical precision and visualization, leading to improved patient outcomes [40]. Wearable devices offer real-time monitoring and diagnostic capabilities, ranging from heart rate variability assessment to wearable defibrillator technology, enhancing patient safety and intervention efficacy [41]. Nanotechnology emerges as a transformative tool for disease detection and treatment, leveraging semiconductor nanocrystals to enable highly sensitive biological imaging [42]. Quantum dots, for instance, enable precise disease identification with superior accuracy compared to conventional methods, thus revolutionizing diagnostic practices [43]. Incorporating Industry 4.0 technologies into healthcare systems yields tangible benefits, from more effective diagnoses to precise clinical interventions and treatments. This technological integration marks a significant advancement toward achieving optimal healthcare delivery outcomes.

4.4. Effect on the Efficiency of Healthcare Systems

Efficiency in healthcare, as defined by Buder and Felden (2012), revolves around optimizing resource utilization to maximize results [44]. This encompasses technical efficiency, allocative efficiency, and economic efficiency, as outlined by Farrel (1957) [45]. Technical efficiency measures the output obtained from given inputs, while allocative efficiency ensures optimal resource allocation, and economic efficiency balances cost minimization with output maximization, as elucidated by Afonso & Fernandes (2008) [46]. In examining efficiency within healthcare, Nunes (2016) highlights the importance of technical efficiency in utilizing available resources to achieve desired outcomes [47]. Magnussen (1996) emphasizes allocative efficiency, focusing on the ideal distribution of production factors to maximize output. Economic efficiency, as noted by Afonso and Fernandes (2008), amalgamates technical and allocative efficiency to minimize costs while maximizing production and revenue [46,48]. In our study, Industry 4.0 technologies were found to enhance efficiency across health systems. They bolster technical efficiency by reducing error rates and optimizing resource utilization, thereby promoting allocative efficiency. Moreover, they contribute to economic efficiency by maximizing financial resources [49,50].

Industry 4.0 technologies, including IoT, AI, ML, BD, and Robotics, play pivotal roles in reducing medical errors. These errors, such as medication administration errors, are significant challenges in health systems, leading to adverse effects and increased hospitalization durations [51]. Technologies like AI and ML enhance predictive capabilities, aiding in treatment decisions and reducing errors [52]. Furthermore, Industry 4.0 technologies optimize human resources by automating repetitive tasks, allowing healthcare professionals to focus on patient care [53]. This leads to increased employee satisfaction and motivation, ultimately improving healthcare services [4,54]. Administrative tasks, which consume a significant portion of healthcare professionals' time, are streamlined through Industry 4.0 technologies, enabling more direct patient interaction [6]. While machines reshape healthcare professionals' roles, they empower them to deliver compassionate care amidst growing workloads [55]. Moreover, Industry 4.0 technologies expedite information processing, enhancing patient care and reducing time consumption [6,50]. Financially, these technologies generate substantial benefits by automating processes, reducing costs, and increasing productivity [56]. Blockchain, AI, robotics, IoT, wearables, telemedicine, and 3D printing are cited as transformative technologies driving cost reductions and efficiency improvements in healthcare systems globally [57, 58]. From reducing hospitalizations to customizing medical devices, these technologies offer promising avenues for maximizing financial resources and improving patient outcomes [59]. In summary, Industry 4.0 technologies hold immense potential for enhancing efficiency across health systems, from error reduction to resource optimization, ultimately leading to improved patient care and cost savings.

5. CONCLUSIONS

In conclusion, our research paints a compelling picture of the profound changes brought about by the 4IR in health systems. Our insights reveal the critical factors driving the integration of 4.0 technologies, including the imperative for skilled professionals and supportive interoperability policies. Notably, the transformative potential of technologies like IoT, Big Data, AI, and Robotics is evident in the significant cost reductions they enable, alongside the enhancement of management practices and healthcare delivery. Moreover, these innovations pave the way for the efficient utilization of human and financial resources, a reduction in error rates, and a remarkable acceleration of processes across the healthcare landscape. With these findings, we glimpse a future where healthcare is not just transformed, but optimized to unprecedented levels, promising improved outcomes for all stakeholders involved.

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