Routledge International Studies in Health Economics

THE DIGITAL TRANSFORMATION OF HEALTHCARE

HEALTH 4.0

Edited by Marek Ćwiklicki, Mariusz Duplaga, and Jacek Klich

ROUTLEDGE

The Digital Transformation of Healthcare

Health 4.0 is a term that has derived from the Fourth Industrial Revolution (Industry 4.0), as it pertains to the healthcare industry. This book offers a novel, concise, but at the same time, broad picture of the challenges that the technological revolution has created for the healthcare system.

It offers a comprehensive view of health sector actors' interaction with the emerging new technology, which is disrupting the status quo in health service delivery. It explains how these technological developments impact both society and healthcare governance. Further, the book addresses issues related to key healthcare system stakeholders: the state, patients, medical professionals, and non-governmental organizations. It also examines areas of healthcare system adaptiveness and draws its conclusions by analysing recent health policy changes in different countries across the Americas, Europe, and Asia. The authors offer an innovative approach to the subject by identifying the critical determinants of successful implementation of the Fourth Industrial Revolution's outcomes in practice, on both a macro- and microlevel. The macrolevel analysis is focused on essential factors of healthcare system adaptiveness for Health 4.0, while the micro-level relates to patients' expectations with a particular emphasis on senior citizens.

The book will appeal to academics, researchers, and students, across a wide range of disciplines, such as health economics, health sciences, public policy, public administration, political science, public governance, and sociology. It will also find an audience among healthcare professionals and health and social policymakers due to its recommendations for implementing Industry 4.0 into a healthcare system.

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List of abbreviations

3D	three-dimensional
3DP	three-dimensional printing
4IR	Fourth Industrial Revolution
AAL	Ambient Assisted Living
AI	Artificial Intelligence
AR	augmented reality
BD	Big Data
BIT model	Behavioural Interventional Technology model
C2C	consumer-to-consumer
C2P	consumer-to-professional
CAGR	compound annual growth rate
CC	cloud computing
CFC	cloud and fog computing
CHESS	Comprehensive Health Enhancement Support System
COPD	chronic obstructive pulmonary disease
CPS	Cyber-Physical Systems
DHT	Digital Health Technologies
DL	deep learning
EHR	Electronic Health Records
EM RAM	Electronic Medical Record Adoption Model
EPHO	essential public health operation
FG	Fog Computing
FP	Framework Programmes
GDP	Gross Domestic Product
GP	general practitioner
GPRS	general packet radio service
GPS	global positioning system
HAL	Hybrid Assistive Limb
HCPS	Health Cyber-Physical Systems
HE	human enhancement
HIMSS	Healthcare Information and Management Systems Society
HIPAA	Health Insurance Portability and Accountability Act

HTA	Health Technology Assessment
ICDs	implantable cardiovascular defibrillators
ICT	Information and Communication Technologies
INAHTA	International Network of Agencies for Health Technology Assessment
IoHT	Internet of Health Things
IoMT	Internet of Medical Things
IoNT	Internet of Nano Things
IoT	Internet of Things
ITU	International Telecommunication Union
LPWA	Low-power wide area
MBps	megabits per second
MICT	Medical Information and Communication Technologies
m-IoT	Internet of mobile health Things
MIS	minimally invasive surgery
ML	machine learning
NASA	National Aeronautics and Space Administration
NGS	next generation sequencing
NIST	National Institute of Standards and Technology
OECD	Organisation for Economic Co-operation and Development
OOP	out-of-pocket
P2C	professional-to-consumer
P2P	professional-to-professional
P4 medicine	predictive, preventive, personalised, and participatory medicine
PDA	personal digital assistants
PE	patient empowerment
PeOPLe	Person-centred Open Platform for Wellbeing
PHR	personal health records
POCUS	point-of-care ultrasonography
TEMPiS	Telemedic Pilot Project for Integrative Stroke Care
TRCs	Telehealth Resource Centres
USSR	Union of Soviet Socialist Republics
VR	virtual reality
WHO	World Health Organization
WIoT	Wearable Internet of Things

Preface: The Fourth Industrial Revolution and healthcare

Marek Ćwiklicki, Mariusz Duplaga, and Jacek Klich

The Fourth Industrial Revolution (4IR) unfolding before our eyes is the driving force behind changes that directly and indirectly affect all the spheres of human life. Its sweeping impact is vividly illustrated by the nested interactive graph prepared by the World Economic Forum (WEF1). It is quite significant that in the seven impact areas of the 4IR highlighted in its inner ring (Technology Access and Inclusion, Technology Innovation, Frontier Technologies, Ethics and Identity, Agile Technology Governance, Agency and Trust, and Demanding New Skills) no mention is made of health. Moreover, as regards Frontier Technologies, only one of its 10 links (to the groups of issues flagged in the outer ring) is directly related to health (Precision Medicine). It is even more surprising that the category most closely aligned with health, i.e. the Future of Medicine and Healthcare, links only to Ethics and Identity (WEF2). In consequence, one may be left with the impression that the impact of the 4IR (via new products, devices, technologies, or artificial intelligence [AI], i.e. the groups of factors highlighted in the interactive graph cited above) on health is relatively small.

The authors of this book set out to demonstrate that the 4IR has a large and growing impact on the healthcare system, public health, and individual health; moreover, it not only triggers structural changes in the healthcare system as such but also represents a turning point in the history of humans as a species.

The main concepts and technologies shaping the 4IR find their way into healthcare and medicine, gradually changing the way healthcare services are delivered and medical products are manufactured. The cyber-physical systems (CPSs) as well as the Internet of Things (IoT), cloud computing (CC) and big data (BD) analytics are listed as the main technologies that shape the landscape of Industry 4.0.

The CPSs are perceived as a technology that permits the integration of computation and physical processes; in other words, it links the virtual cybernetic world with the world of physical reality (Lhotska, 2020). Health CPSs (HCPS) are a subtype of CPSs that rely on intelligent communication between medical devices and computers (Jain et al., 2021). The examples of currently available HCPS solutions include electronic medical records, applications to support daily living, monitoring the patients' health status, or controlling the intake of prescribed medications (Haque et al., 2014).

The IoT, perceived as one of the pillar technologies of Industry 4.0, brings great opportunities to the delivery of modern healthcare services. Essentially, the IoT is a huge network of interconnected objects, both devices and people, which can communicate with one another (Lakhwani et al., 2020). Wireless sensors capable of monitoring various signals originating from the human body or from the surrounding environment are particularly important for the development of innovative solutions for healthcare. Progress in the domain of e-health resulted in the implementation of telemonitoring systems which usually relay a limited set of biosignals or other parameters needed to track the course of specific diseases. The rise of mobile health technologies associated with progress in smartphones, smart bands, and other kinds of wearables equipped with a whole array of embedded sensors has led to more complex ways of monitoring people's health status and their activity regardless of where they may be during their daily routine. The potential of the IoT relies on its capacity to integrate a considerable amount of data coming not only from devices carried by individuals but also from sensors embedded in the furniture and equipment used at homes (e.g. refrigerators) and from devices used to monitor the external environment, such as those that measure air pollution levels. Depending on its main aims, several terms have been proposed for a system used in healthcare and based on the IoT technology, including general ones, such as the Internet of Health Things (IoHT) or the Internet of Medical Things (IoMT), and several more specific ones, such as the Wearable Internet of Things (WIoT), the Internet of mobile health Things (m-IoT), or even the Internet of Nano Things (IoNT) (Hiremath et al., 2014; Istepanian et al., 2011; Omanović-Mikličanin et al., 2015; Terry, 2016). The fact that so many terms apply to health-related IoTs certainly results from a concatenation of advanced technologies and reflects a high interest of technical and medical communities in the development of services that benefit from them.

The CC is another pillar technology for Industry 4.0 which transforms the way healthcare services are delivered. It is defined as "a system that enables ubiquitous, convenient, on-demand network access to a common pool of configurable computing resources" (Mell & Grance, 2011). The CC is essentially a new model of accessing hardware, software, and data in order to run proprietary applications. The user – a healthcare institution – accesses the IT infrastructure and is charged only for the actual usage of the resources (Sultan, 2014). The CC facilitates access to advanced IT solutions for healthcare providers; however, this can be subject to special restrictions due to legal requirements applicable to the health sector (Gia et al., 2015).

The expectations associated with the exploration of BD in medicine and healthcare are also quickly rising. Healthcare generates significant amounts of heterogeneous data which, once processed, promise to deliver advanced diagnostic capacities and the ability to deliver individualised therapies.

Furthermore, AI combined with machine learning (ML) and deep learning (DL) is perceived as the key strategy for analysing BD sets in medicine and healthcare services.

Apart from the pillar technologies mentioned above, there are many other areas of technical progress that profoundly affect the healthcare system. Progress in robotic surgery, leading to daring projections about automatic procedures (Bhandari et al., 2020), is well aligned with the integration of virtual and physical worlds offered by the CPS. From the very first applications of robots in surgery in 1980s, substantial advances have been made in the ergonomics of systems offered to surgeons (Jain et al., 2020), the support for human interactions with robotics tools, and the use of augmented reality (AR) to guide surgeons during procedures (Makhataeva & Varol, 2020). The growing abilities of equipment have led to a renewed interest in the use of AR in medical imaging diagnostics, surgical planning, and navigation (Sutherland et al., 2019). Specific niches for therapeutic interventions based on AR and virtual reality are also emerging, among others, in psychiatry (Sutherland et al., 2019).

The exploration of BD sets generated by Internet users gave rise to a new area called infodemiology (Eysenbach, 2009). It is based on the observation that a large proportion of information supply and demand has a health-related context. Unstructured user contributions in social media and on other websites may also be used to implement the so-called infoveillance algorithms which make it easier to anticipate emerging epidemic threats or assess the most pressing health needs of a given population. The analysis of these using AI is expected to have a significant impact on the strategies of monitoring population health, including during pandemics (Bragazzi et al., 2020; Dolley, 2018).

The concept of precision medicine (as shown in the cited WEF graph) draws on the functionalities provided by three-dimensional printing (3DP), including patient-specific implants, controlled delivery of medication, or patient-specific *in vitro* models for assessing the response to pharmaceutical agents (Prendergast & Burdick, 2020). Although the most common real-life applications of 3DP in healthcare include 3D models printed for educational purposes and to some extent, 3D implants, the opportunities resulting from the increasing availability of body parts printed with biological materials, or even viable cells, seem to be the most anticipated (Kačarević et al., 2018).

This broad discussion of the impacts of the 4IR on health explains why the term Health 4.0 appears in the title of this book. Given the enormous scope of the 4IR's effect on the healthcare system, it seems reasonable to take a broader perspective to review the factors that emerge from the 4IR to shape the organisational and financial aspects of the healthcare system now and in the near future.

In the current literature, the technological angle prevails with the healthcare system and its main actors – society and policymakers – being afforded only cursory treatment. In our study, we intend to focus on patients, societies, and governments. The application of systemic and macro approaches allows us to combine individual studies into a fresh perspective on Health 4.0.

This book consists of 15 chapters. Chapter 1, The Fourth Industrial Revolution and the Healthcare System, depicts the 4IR phenomenon in the context of the challenges it poses to healthcare systems. The list of these challenges includes new medicines and medical technologies, new medical devices, nanotechnology and genetic engineering, implants, telemedicine and e-health, AI, and human enhancement. The concept of Health 4.0 is also defined and its four components are discussed. Throughout, Chapter 1 introduces the issues to be addressed in more depth in subsequent chapters.

Chapter 2, entitled The Transition from Telemedicine and e-Health to Health 4.0, charts the evolution from telemedicine to Health 4.0. It explores from a historical perspective telemedicine and telehealth, e-health and m-health, and the transition from Health 1.0 to Health 3.0, to end with Health 4.0 as part of the 4IR.

Technologies that underlie Health 4.0 are the focus of Chapter 3 (Technologies Enhancing Health 4.0). It serves as an introduction to the areas mentioned above: CPSs, the IoT, cloud and fog computing (CFC), big data analysis and AI, blockchain technology, robotic systems, virtual reality and AR, and 3D printing.

While the previous chapter provides a general description of the technologies in question, Chapter 4 (The Landscape of Health 4.0 – Areas of Application) presents examples of their practical use in the healthcare system including the concept of 4P medicine, remote monitoring, ambient assisted living, robotic surgery, and the issues of public health and epidemic surveillance especially relevant in the context of the SARS-CoV-2 pandemic.

Patient empowerment (PE) in the healthcare system is one of the four components of the concept of Health 4.0 discussed in this book. This issue is dealt with in Chapter 5 (Patient Empowerment in Health 4.0). Apart from defining PE, it explores the relationship of PE to Health 4.0 and discusses modelling the impact of ICT on PE, technologies for PE, personal health records, remote monitoring, electronic patient-physician communication, and participating in online patient communities.

New information technologies and applications brought about by the 4IR can improve the quality of life for people with disabilities, an issue addressed in Chapter 6 entitled People with Disabilities in the Information Society. After defining the relevant concepts, the authors briefly review the current disability models and go on to discuss the unfulfilled promises of digital inclusion as well as the benefits and risks associated with the Internet use.

Along with people with disabilities, senior citizens comprise the second group that may benefit from the achievements of the 4IR. They are discussed in Chapter 7 (Health 4.0 for the Elderly: New Challenges and Opportunities for a Smart System) and include the issues associated with the ageing population and digital transformation from a societal perspective, the factors that need to be taken into account when introducing the digital transformation into senior care as well as the author's original proposal for a new paradigm of a senior citizen–friendly healthcare system.

Chapter 8, entitled Co-creation in Health 4.0, follows up on the contents of Chapter 5. It introduces and develops the theme of active patient participation in product creation, identifying the stages of planning, design, implementation/delivery, and maintenance, along with references to the current trends in healthcare. The chapter ends with a presentation of models of consumer value co-creation in healthcare.

Chapter 9 (The Implementation of New Technologies in Health 4.0 in Selected Countries) discusses the ranking of the top 10 countries using the World Index of Healthcare Innovation 2020, followed by more detailed profiles of four countries (USA, Germany, Japan, and Australia) in terms of their achievements in the area in question. The chapter concludes with a review of the four key success factors in implementing Health 4.0 as well as the risks and problems associated with it.

The issues associated with implementing Health 4.0 in practice are addressed in Chapter 10, entitled The Key Factors of the Healthcare System's Adaptiveness for Health 4.0. It proposes six factors considered important in this regard - human capital, information and communication technologies, social capital, financial resources, governance, and legal regulations - and briefly characterises each of them.

Finance, one of the factors mentioned in the previous chapter, is dealt with in more detail in Chapter 11 (Financing Health 4.0). It looks at healthcare spending in OECD countries in 2000-2019 and outlines the prospects for change in healthcare financing in connection with the implementation of Health 4.0. The author argues that even though in post-socialist countries the share of out-of-pocket (OOP) expenses in total health spending is already significant, the rapid progress in the introduction of new medicines, medical devices, and technologies, but above all human enhancement services, is likely to increase even further. This may widen the already large gaps in access to health services and destabilize not only the healthcare system in the foreseeable future.

Chapter 12, entitled Law and Health 4.0, takes up and expands on the second of the six factors identified in Chapter 10 that affect the implementation of Health 4.0, i.e. the legal regulations. The author focuses on the legal framework for the use of AI, nanotechnology, genomics, and genetic engineering.

The next chapter (Human Capital vs. Health 4.0) explores the issue of social capital, the third factor identified in Chapter 10. The author addresses the key challenges posed by the 4IR to selected stakeholders in the healthcare system, i.e. patients (the demand side) and health professionals (the supply side), especially in the context of the virtually unlimited access to information on the Internet. The authors demonstrate how Health 4.0 technologies (including telemedicine) can improve the utilisation of staff resources and help alleviate its shortfalls. The determinants and barriers to the use of modern devices and applications, including AI, are also discussed. In the authors' opinion, the curricula of medical schools (as the key health professionals) must be updated with a view to developing communication, or more broadly, soft skills, and digital skills among physicians and nurses.

Chapter 14, The Role of Civil Society Organisations in Health 4.0 Service Delivery: Examples from Poland, refers to the fourth constitutive feature of Health 4.0 highlighted in Chapter 1, i.e. PE in the healthcare system and the development of civil society. It presents the findings of a pilot study conducted among six non-governmental organisations in Poland, which lead to the identification of a range of key issues associated with the implementation of Health 4.0 principles.

Chapter 15 (Recommendations for Implementing Industry 4.0 in the Healthcare System) offers guidelines for the major stakeholders in the healthcare system, i.e. government (state authorities), patients, health professionals, and non-governmental organisations.

The contents outlined above are addressed to a broad readership, ranging from central and regional health policymakers, healthcare providers (managers and health professionals), health science, and medical students, to individuals interested in technological progress and innovation in the healthcare system. We also hope that the book will be of interest to students, scholars, and practitioners working in health and social policy, political science, public management, and governance.

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1 The Fourth Industrial Revolution and the healthcare system

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Introduction

The Fourth Industrial Revolution (4IR) profoundly affects not only service production and provision but also business, governments, people, and the entire social sphere (Schwab, 2016a). The aim of this chapter is to explore the phenomenon and nature of the 4IR (the first part of the chapter) in the context of the challenges it poses (and will pose) to the health system (the second part). The concept of Health 4.0 is then used to interpret these challenges (the third part). The author sets out to demonstrate that the 4IR has initiated a new stage in human development, which will require far-reaching changes in the organisation and financing of the healthcare system.

The Fourth Industrial Revolution and its dimensions

The concept of the Fourth Industrial Revolution

The 4IR is understood here as an economic and social phenomenon driven, among others, by the development of artificial intelligence (AI; Dahl, 2019), robotics, the Internet of Things (IoT), autonomous vehicles, 3D printers, nanotechnology, additive manufacturing, neurotechnology, biotechnology, materials engineering, energy storage, quantum computers, etc. Although the 4IR is *in statu nascendi*, it is rapidly developing and is subject to intensive research. Research findings show that it is having an increasing impact on all the dimensions and aspects of human life, including the healthcare system (Nadella, 2018, p. 9). As Karl Schwab puts it, we will have to "understand and shape the new technology revolution, which entails nothing less than a transformation of humankind" (Schwab, 2016a, p. 7). The phrase "transformation of humankind" is by no means an exaggeration in this context.

The 4IR entails far-reaching and system-wide changes due to its three essential characteristics: (a) high pace; (b) breadth and depth; and (c) a sweeping impact on all the spheres of human life. These changes result in, among other things, "a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres" (Schwab, 2016b). The interpenetration of

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these three worlds with sophisticated technologies can be considered as the specific difference between the 4IR and the previous three industrial revolutions. In such a context, of key importance are the consequences of these processes, including, in particular, the gradual disappearance of the boundary between man and machine. This is a two-way process, which involves, on the one hand, equipping machines with functions and characteristics inherent to humans (using AI) and, on the other, equipping humans with a range of devices (including implants) and/or applications that expand their physical and cognitive capabilities to an unprecedented degree, known in the literature as human enhancement (HE).

The impact of the Fourth Industrial Revolution on the environment and human life

The 4IR leads to profound changes in the environment and human life.[1] Its impact on industry and industrial relations (Badri et al., 2018; Martinez et al., 2019; Schwab, 2016a; Schwab, Davis, 2018), trade (Kaur, Kaur, 2018), and education (Gleason, 2018) has been intensively studied, and its scope as an object of research is constantly expanding.

The World Economic Forum identifies eight areas through which the 4IR affects economies and societies: ethics and identity, agile technology management, inequality, business disruption, labour market disruption (including worker skills), security and conflict, innovation and productivity, and technology connectivity/interpenetration. Each of these areas is subsequently associated with more narrowly defined fields and phenomena (based on functional relationships and dependencies). Their list is quite long (currently, it consists of 31 items and is growing as our knowledge develops) and is comprised of, among others, values, biotechnology, global governance, justice and judicial infrastructure, cybersecurity, drones, circular economy, the future of economic growth, mental health, advanced materials, 3D printing, information technology, entrepreneurship, international security, public finance and social protection, and geopolitics (World Economic Forum, 2019).

It is noteworthy that relatively little attention (as emphasised by e.g. Schwab, 2016a; WHO, 2011) is devoted to tracking and analysing the current and expected future impacts of the 4IR on health or, more broadly, on the healthcare system. This book aims to contribute to filling this research gap.

The impact of the Fourth Industrial Revolution on health

The recently published research findings on the impact of the 4IR on health have made it possible to identify its five key aspects, namely “the impact on healthcare efficiency and effectiveness, the impact on government action, the impact on human resources, the impact on health system organisation, and the financial impact on the health sector” (Castro e Melo and Faria Araújo, 2020). Given the current status of the 4IR as an emerging phenomenon,