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Review

# Digital twins in healthcare administration: A systematic review on novel approaches to management and planning

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**Abstract:** The article presents a literature review on the application of digital twin technology in healthcare administration over the past decade. This review examines the potential applications of digital twins at different levels of healthcare management. The formation and global development of digital twin technology are discussed. Examples of the use of digital twins in the management of healthcare institutions and healthcare processes are specified, and their advantages and future prospects are analyzed.

**Keywords:** digital twins, personalized medicine, information technology, healthcare administration.

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## Introduction

Digitalization is rapidly developing, covering all areas of modern society. Digitalization, based on automation, computing and information processing, arises from the expanding field of computer technology and communications. The modern healthcare system is undergoing a similar process of digital transformation, where the integration of information technology (IT) has become indispensable. Complex systems such as the healthcare system require fast and efficient management and planning. This demand stimulates the development of digital modeling technologies that simulate system performance to predict the results of various management decisions in a virtual environment, thereby allowing the selection of optimal management strategies. Such technologies significantly reduce time and financial costs.

The healthcare system, as one of the most dynamic sectors of the national economy, requires enhanced planning and management mechanisms supported by simulation modeling. The COVID-19 pandemic has highlighted the critical importance of advanced IT and decision-making systems. These systems facilitate tracking and predicting the spread of the epidemic, allow for rapid response to outbreaks, optimize patient routing and effectively manage healthcare resources [1, 2].

The term *digital twin* was first coined in the 1990s [3]. The technology initially emerged in industrial and engineering settings. Industrial digital twins have two key features. First, they rely on mechanical models of physical systems to simulate their behavior. Second, they are dynamically calibrated against the system to predict its performance and identify the need for interventions such as preventive maintenance [4].

The first attempts to apply digital twin technology in healthcare were made decades ago. One of the most notable pilot projects was *Archimedes*, which focused on the treatment of patients with diabetes [5]. Another example is *DISCIPULUS*, a project implemented in the European Union under the FP7 ICT for Health Program (2011-2013). Its main goal was to develop a roadmap for the creation of a digital patient known as *medical avatar*, which would serve as a virtual copy of a real patient, allowing various medical interventions to be simulated to identify optimal treatment strategies [6].

In 2015, a working group was established in the United States to study the potential of digital twin technology in advancing personalized medicine [7]. Following this, in 2018, the Food and Drug Administration (FDA) initiated the implementation of digital approaches to testing and monitoring new medical devices and medicinal drugs [8]. In Russia, a similar initiative was launched in 2021 by the Ministry of Healthcare. As part of the national healthcare modernization project, the ministry proposed creating a digital analog of a real patient to consolidate all patient data into a single digital resource in order to improve patient management and optimize the provision of medical care [9].

Thus, the use of digital twins has become a global trend with promising results. Recently, digital twin technology has evolved into a fast-growing industry, and its market size is projected to reach $ 183 billion by 2031 [10]. Gartner analysts included digital twin technology in their list of the top ten strategic technology trends of 2019. By 2020, in its report (*Hype Cycle for Healthcare Providers, 2020*), the company specifically noted a surge in interest of using digital twins in healthcare [11, 12].

This study *aims* to examine the current advances and potential applications of digital twins in healthcare administration.

### Materials and Methods

The search for publications was conducted in the Russian Science Citation Index (RSCI), PubMed and Google Scholar databases using the following keywords: digital twin, personalized medicine, information technology and healthcare administration. The search was limited to publications covering the period of the past 10 years. The most relevant sources, in the authors' opinion, were selected for the analytical review. The analyzed publications included observational and experimental original studies, as well as systematic reviews. In accordance with the objectives of this systematic review, a total of 428 published sources were reviewed that met the search criteria, of which materials from 38 sources were included in the article.

### Results

***The concept of digital twins***

Digital twins originate from simulated environments created by the U.S. National Aeronautics and Space Administration (NASA) in the 1970s to monitor inaccessible physical environments, such as spacecraft in flight. One of the earliest known applications of digital twin technology was demonstrated during the Apollo 13 mission, when an oxygen tank exploded two days after launch. Engineers from NASA's Mission Control Center in Houston, TX, USA, were able to simulate the situation and test possible solutions using a virtual model of the spacecraft. An optimal solution was identified, allowing the astronauts to build a makeshift air purifier using onboard materials, which ultimately ensured the safe return of the Apollo 13 crew to Earth [13]. This approach was widely recognized as an early prototype of digital twin technology, preceding the widespread adoption of the concept [14].

**Table 1. Digital twins in healthcare administration**

| *##* | *Hierarchical level of digital model (Facility/city/region/corporation)* | *Citation* | *Project name/ developer/journal* | *Results* |
|---|---|---|---|---|
| 1 | City | El Azzaoui A., et al. (2021) [24] | *Advanced Multimedia and Ubiquitous Engineering* | The model predicts the spread of COVID-19 in a city. By analyzing smartphone user data and geographic information systems (GIS), it can track patient flows and identify contact networks of infected individuals. |
| 2 | City | Kamel Boulos M.N., et al. (2021) [25] | mHealth | The platform is designed to plan and track physical activity while maintaining data privacy. It also provides accurate data for public health decision-makers on population-level physical activity metrics derived from aggregated user data. |
| 3 | Medical facility | George Lawton (2021) [28] | Atlas Construction | The platform optimizes design, procurement, and construction processes to speed up hospital construction. It is based on the Oracle Cloud platform and the Primavera Unifier asset lifecycle management service. |
| 4 | Medical facility subdivision | George Lawton (2021) [28] | Artificial | A digital twin of a laboratory designed to speed up novel drug testing, improve the reproducibility of experiments, and reduce testing costs. |
| 5 | Medical facility | https://web.musc.edu/-/sm/enterprise/about/leadership/institutional-offices/communications/f/catalyst-pdf-archives/2019-catalyst-news-archives/catalyst-8-23-19.pdf [29] | Siemens Healthineers, Medical University of South Carolina, USA | A digital model designed to optimize hospital management processes and reduce the time it takes to provide care to patients with acute stroke. |
| 6 | Medical facility subdivision | https://www.siemens.com/us/en/company/press/siemens-stories/usa/digitalized-medicine-siemens-tech-accelerates-vaccine-production.html [30] | Siemens Healthineers, Medical University of South Carolina, USA | A digital twin of a vaccine production line enables the design of microfluidic lines, scaling processes, and reducing the time it takes to industrialize vaccine production. |
| 7 | Medical facility | https://www.gehccommandcenter.com/digital-twin [31] | GE Healthcare Camden Group | A digital module for planning bed capacity, staff schedules, and operating room use. The platform allows testing various management solutions in a virtual environment and choosing the best option without launching a pilot project. |
| 8 | Corporate (technical support for multiple centers) | https://www.feops.com/src/Frontend/Files/MediaLibrary/13/feops-press-release-20210527-final.pdf [32] | Philips | A preventive maintenance program for timely diagnostics of malfunction and adjustments to operating modes. |
| 9 | Regional | Liu Y., et al. (2019) [33] | CloudDTH | A cloud platform for managing the health of the elderly. The platform aims to solve the problem of monitoring the health of the elderly in real time and increasing the accuracy of crisis alerts through the use of digital twins, cloud computing, the Internet of Medical Things (IoMT), and big data. |
| 10 | City | Deren L., et al (2021) [34] | Computational Urban Science | A digital model of a *smart city* can predict disease outbreaks (e.g. COVID-19), assess the load on healthcare facilities, and quickly identify contact networks based on a large spatiotemporal patient database updated from various sources. |

Simulation modeling of the behavior of an object or system is a high-fidelity virtual model built on the transfer of data from real objects and based on digital twin technology [15]. The literature distinguishes two main approaches to the implementation of simulation modeling in healthcare. The first approach uses simulation modeling to predict the spread of diseases, allowing for the prediction of disease dynamics, optimization of response strategies, and the efficient allocation of human and material resources. The second approach focuses on modeling the operations of healthcare institutions to improve the overall efficiency of healthcare facilities [16].

The concept of a digital twin, originally introduced in manufacturing as a *mirrored spaces model*, was later applied to medicine. The fundamental idea of digital twins is attributed to Professor Michael Greaves of the University of Michigan. In 2002, he described a digital model consisting of three components: a physical product in real space, a virtual product in virtual space, and the data that connects them [17, 18]. This technology has been successfully applied not only in organizing technological processes in industrial enterprises, but also in the development of spacecraft simulators. By 2010, the concept officially acquired a name of a *digital twin* during a NASA project to create digital simulators for spacecraft [19]. A digital twin is a virtual copy of a real-world object, process, or system that reflects its dynamic functionality based on input data and artificial intelligence technologies. It is capable of predicting the behavior of its physical counterpart in real time, identifying and correcting potential errors [20, 21, 22].

Digital twin technology is seen as a promising direction for developing new approaches to analyzing patient data, as well as modeling and testing various medical procedures and healthcare management processes. Currently, digital twin technology is being implemented in three main areas: (1) the development of personalized medicine, (2) the development and implementation of new pharmaceuticals and services, and (3) the use of digital twins in healthcare management. The application of this technology is rapidly expanding due to advances in artificial intelligence, data transmission, augmented reality and virtual reality, which can improve the delivery of health care in both real-life clinical practice and healthcare management [23]. This trend is expected to shift the focus from disease treatment to early (preclinical) prediction and prevention of diseases, as well as timely optimization of health system resources in an ever-changing environment.

### *Digital twin technology in healthcare administration*

The use of digital twins in public health care is based on population health assessment. The global impact of the COVID-19 pandemic has significantly accelerated the development of predictive virtual models powered by digital twin technology. An example of such models is a study in which researchers used smartphone data to track COVID-19 symptoms and potential contacts of each user. By analyzing real-time data on patient location, movement, comorbidities, and disease severity, they developed a virtual model and integrated it into local healthcare information systems to monitor and update patient flows in real time. However, a key limitation of this system is the inability to modify previously entered data [24]. Thus, digital twin technology brings a new level of accuracy to population health data, especially in tracking the spread of epidemic processes.

Such systems can also be used to assess population health, identify disease risk factors, and determine the optimal placement of wellness facilities such as gyms to prevent physical inactivity, and public schools and outpatient clinics to ensure comprehensive coverage of the population [25]. The growing popularity of the Internet of Things (IoT) has led to increased use of a variety of personal sensors, such as temperature, humidity, air quality, and lighting sensors. Collecting such data can be valuable for population-level decision-making related to environmental factors, including issues such as environmental racism and geographic disparities in health outcomes [26].

At the moment, the market is seeing a growing number of companies developing digital twin technologies in both personalized medicine and healthcare administration. Leading IT giants such as IBM, General Electric, ANSYS Inc., Microsoft, Siemens, Philips, Alibaba, Google, and Oracle are actively working on the development of this technology [27]. Along with with the advances in creating digital avatars of patients, business models for planning and optimizing healthcare costs are also being actively developed. For example, Atlas Construction has developed a digital twin platform for asset lifecycle management in the design, procurement, and construction of healthcare facilities [28]. Siemens Healthineers, in collaboration with the University of South Carolina, has developed a technology for analyzing hospital administration processes to reduce the time required to provide medical care to patients with acute stroke. In addition, the company is also developing digital twins for vaccine production lines. This technology allows for the design of microfluidic lines, scaling up processes, and reducing industrial production time from one year to five months [29, 30]. The platform developed by GE Healthcare Camden Group based on digital modeling and virtualization of healthcare facility management helps minimize costs while improving the quality of medical care. This is achieved by optimizing bed planning, staffing, and the use of operating rooms. The platform allows testing various management solutions in a virtual environment and choosing the best option without the need for a pilot project. Such technologies help save both material resources and time. For example, GE Healthcare Camden Group has developed a digital module to assess the impact of bed configuration on the quality of care and optimize surgical schedules [31]. Philips, one of the world’s largest suppliers of medical equipment, has launched a preventive maintenance program. The program analyzes data from 15,000 medical imaging devices, promptly diagnosing malfunctions and adjusting operating modes in accordance with the needs and conditions of customers [32].

Another area of using digital twin technology in healthcare administration is the development of a virtual model for testing innovative drugs in a controlled environment. Such digital twin of the laboratory allows for the automation of tests and the increase in the reproducibility of laboratory experiments. The market for such solutions exceeds $10 billion. E.g., Artificial raised $21.4 million to develop virtual laboratory software [28]. An example of cloud structures aimed at organizing medical care for patients with a specific disease is the CloudDTH cloud structure (a cloud healthcare system based on a digital model), developed for managing the health of the elderly. The proposed platform is aimed at solving the problem of monitoring the health of the elderly in real time and the accuracy of warning about crisis situations using digital twins, cloud computing, the IoMT, and big data [33].

Deren L. et al. investigated the use of digital twin technology as an integrated component of a smart city in the context of COVID-19. The model can predict disease outbreaks and the burden on healthcare facilities, as well as quickly identify contact circles using a large spatiotemporal patient database updated from multiple sources [34].

Examples of healthcare administration projects using digital twin technology are shown in *Table 1*.

### Discussion

Digital twin technology marks a new era in business process management, especially in healthcare. Rapid advances in IT helped every system and object in the real world to have its own digital footprint. In healthcare, this includes electronic medical records, laboratory and test results, pharmaceutical data, patient movement data, wearable digital health devices, lifestyle and environmental data, and patient routing and facility processes. Analyzing this massive amount of data makes it possible to predict disease progression at the population level and manage the evolution of the healthcare system from individual departments to the global scale.

The application of digital twin technology in medicine goes far beyond modeling healthcare processes. The technology is most commonly used in personalized medicine to create digital avatars of various types (from molecular to organismal) that facilitate a comprehensive understanding of individual disease characteristics, allowing for the modeling, analysis, and prediction of disease progression and treatment outcomes in a virtual environment. Another application of digital twin technology is clinical trials of new treatments or pharmaceuticals. Clinical trials often experience delays in patient recruitment, with approximately 80% of trials experiencing such issues and 20% failing to reach their target number of patients [35]. Digital twin technology can improve the statistical reliability of clinical trials with small sample sizes by creating an unlimited number of virtual copies of real patients and modeling multiple treatment options, as well as reducing the need for animal experiments [36]. In drug/placebo clinical trials, an ethical conflict arises because the treatment may benefit the patient while the placebo does not. By creating multiple digital copies of real patients, a simulated control group (the placebo group) can be formed. This approach has been adopted by UnlearnAI, which has begun using digital twins in clinical trials targeting Alzheimer's disease and multiple sclerosis [37].

Contemporary healthcare system faces numerous challenges. These include rapidly increasing patient demand, increasingly complex clinical practices, outdated infrastructure, space constraints, longer waiting times, and rapid advances in medical technology that require new equipment, patient routing, and care processes. Using digital twin technology, potential solutions can be tested in a virtual environment before their implementation. By applying simulation and analytics, healthcare facilities can predict patient activity and plan capacity according to demand, thereby significantly improving patient care, safety, and quality of care. The ultimate goal of using digital twins in medicine is to optimize the management of medical facilities and other healthcare institutions, coordinate patient care initiatives from a social and demographic perspective, improve healthcare efficiency, save costs, and prevent predictable crises.

The application of digital twins in medical practice is a promising approach that can improve clinical outcomes, optimize healthcare delivery processes, and expand research into the introduction of new pharmaceutical drugs and medical devices [38].

### Conclusion

The use of digital twin technology in healthcare administration is a promising method for planning and managing business processes in medical institutions. This technology allows predicting dynamically changing conditions for the provision of medical care, the needs of the population and potential crises. Management optimization is achieved by choosing the best solution from a variety of virtual model options. Digital models were created for various levels of medical care. However, for further development and widespread implementation of digital twins, uniform standardization and harmonization of data, ensuring confidentiality of information (development of data protection mechanisms) and establishing legal, regulatory and economic frameworks are essential.

**Conflict of interest**

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