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Dijital İkiz Hastaneler: Öngörücü Sağlık Yönetişimi için Algoritmik Replikaların İnşası

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Öz: Günümüz sağlık sistemlerinde karar alma süreçleri; kalıcı kaynak kısıtları, hizmet talebindeki dalgalanmalar, karmaşık ve yüksek riskli hasta profilleri ile çok katmanlı yönetişim yapıları nedeniyle giderek daha karmaşık hâle gelmektedir. Hastane yönetiminde yapay zekâ, büyük veri analitiği ve gelişmiş karar destek sistemlerinin kullanımı hızla artmasına rağmen, bu teknolojilerin bütüncül ve simülasyon temelli bir yönetişim çerçevesine entegrasyonu sınırlı düzeyde ele alınmaktadır. Özellikle finansal, klinik, hasta, risk ve insan kaynağı verilerinin eş zamanlı ve entegre kullanımıyla öngörücü karar alma süreçlerini destekleyen Dijital İkiz Hastane yaklaşımının stratejik yönetişim kapasitesi yeterince tartışılmamıştır. Bu çalışma, dijital ikiz teknolojileri, yapay zekâ destekli karar sistemleri, hastane yönetişimi ve simülasyon tabanlı yönetim yaklaşımlarını kapsayan kavramsal bir anlatı derlemesi olarak tasarlanmıştır. Bulgular, dijital ikiz hastanelerin yalnızca operasyonel verimlilik sağlayan teknik araçlar değil; belirsizlik altında karar alma kapasitesini artıran, yönetsel öngörüyü geliştiren ve senaryo temelli analizlere olanak tanıyan stratejik yönetişim platformları olduğunu göstermektedir. Bu bağlamda çalışma, dijital ikiz hastaneleri öngörü temelli, uyarlanabilir ve dayanıklı sağlık yönetişimi altyapıları olarak yeniden kavramsallaştırarak literatüre katkı sunmaktadır.

Anahtar kelimeler: Yapay zeka, sağlık hizmetleri, hastane yönetimi

Digital Twin Hospitals: Building Algorithmic Replicas for Predictive Healthcare Governance

Abstract: Decision-making in contemporary healthcare systems has become increasingly complex due to persistent resource constraints, fluctuating service demand, heterogeneous high-risk patient profiles, and multi-layered governance structures. Although the use of artificial intelligence, big data analytics, and advanced decision support systems in hospital management has expanded rapidly, their integration into a holistic, simulation-based governance framework remains limited. In particular, the strategic governance capacity of the Digital Twin Hospital concept enabled through the real-time integration of financial, clinical, patient, risk, and human resource data has not been sufficiently explored. This narrative review synthesizes the current literature on digital twin technologies, AI-supported governance systems, and simulation-based hospital management to develop a conceptual framework for Digital Twin Hospitals. The findings indicate that digital twin hospitals should not be viewed merely as tools for operational efficiency, but as strategic governance platforms that enhance decision-making under uncertainty, strengthen managerial foresight, and enable scenario-based analysis. The study contributes to the literature by proposing a governance-oriented conceptual framework integrating simulation and governance dimensions within Digital Twin Hospitals

Keywords: Artificial intelligence, Healthcare, Hospital Administration

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Introduction

In an era marked by escalating pressures on healthcare systems ranging from recurrent pandemics and demographic shifts toward aging populations to persistent fiscal constraints, traditional governance models grounded in retrospective analytics and linear extrapolations are increasingly untenable (World Health Organization, 2021). These models, often siloed by departmental boundaries, exacerbate inefficiencies, with suboptimal decision-making accounting for an estimated 20%–30% of global healthcare waste, including delayed interventions, resource misallocations, and escalated costs (Bruynseels et al., 2018; Corral-Acero et al., 2020). As healthcare leaders navigate this volatility, the imperative for proactive, foresight-oriented paradigms has never been more acute, particularly in hospital settings where interconnected operations demand holistic oversight.

Enter the concept of digital twins (DTs): high-fidelity virtual replicas of physical assets or systems that leverage real-time data synchronization, advanced simulations, and predictive modeling to mirror and anticipate real-world behaviors (Grieves & Vickers, 2017). Originating in aerospace and manufacturing, where DTs have substantially reduced prototyping requirements through iterative virtual testing (Tao et al., 2018), this technology has rapidly permeated healthcare. Initial applications focused on micro-scale personalization, such as organ-specific twins for cardiovascular disease management, which demonstrate high predictive performance in simulating therapeutic responses (Corral-Acero et al., 2020). More recently, meso- and macro-level implementations have emerged, including population health twins for epidemic forecasting and operational replicas for supply chain resilience, as evidenced in post-COVID-19 pilots that contributed to mitigating ventilator shortages during pandemic conditions via agent-based simulations (Sun et al., 2023; Junga et al., 2024).

Yet, despite these advancements, a profound gap endures in the healthcare DT landscape: the paucity of integrated, ecosystem-wide hospital twins that transcend clinical silos to encompass the multifaceted governance domains of finance, patient flows, clinical workflows, risk mitigation, and human resources (Bruynseels et al., 2018). Current DTs, while innovative, remain fragmented clinical models rarely interface with financial forecasting engines, and risk assessments overlook personnel dynamics, leading to blind spots in executive decision-making (National Academies of Sciences, Engineering, and Medicine, 2024). This fragmentation is particularly salient in governance contexts, where reactive strategies during crises, such as the 2020–2022 global health disruptions, contributed to increased mortality risks in under-resourced healthcare facilities due to unmodeled interdependencies (World Health Organization, 2021; World Health Organization, 2024). Moreover, ethical and scalability challenges, including data privacy under frameworks like the EU's AI Act and algorithmic biases in underrepresented cohorts, further hinder adoption (Bruynseels et al., 2018; Junga et al., 2024).

This conceptual paper addresses these lacunae by proposing the paradigm of Digital Twin Hospitals (DTHs): comprehensive algorithmic replicas that fuse multi-modal data streams encompassing financial ledgers, electronic health records (EHRs), IoT sensor feeds from clinical environments, probabilistic risk ontologies, and HR analytics into a unified, bidirectional simulation architecture (Grieves & Vickers, 2017; Tao et al., 2018). Unlike extant DTs, DTHs are engineered for managerial foresight, functioning as virtual "decision sandboxes" where administrators can orchestrate "what-if" scenarios, such as reallocating staff during surge events or hedging budgets against regulatory flux, all while quantifying cascading impacts across governance pillars. Grounded in foresight methodologies like scenario planning and horizon scanning, DTHs enable probabilistic foresight, shifting healthcare governance from hindsight-driven corrections to preemptive optimization (Miles et al., 2008; Bruynseels et al., 2018).

At the heart of our framework lie two novel constructs designed to operationalize this vision: the AI Simulation Board (AISB), a collaborative, AI-moderated virtual platform that democratizes multi-stakeholder scenario deliberation through explainable simulations; and Predictive CEO Decision Rooms (PCDRs), immersive augmented reality interfaces tailored for executive-level strategic foresight, integrating neuro-symbolic AI to personalize risk-appetite-aligned forecasts (Junga et al., 2024; World Health Organization, 2024). These innovations draw on interdisciplinary synergies blending systems engineering, generative AI, and health policy to foster resilient systems that not only withstand disruptions but derive adaptive strengths from them (Vig et al., 2019).

Through this lens, we interrogate the transformative potential of DTHs for predictive healthcare governance, wherein decisions are audited via simulation trails, equity is simulated across demographics, and resilience is benchmarked against black-swan contingencies (National Academies of Sciences, Engineering, and Medicine, 2024). This work contributes to the burgeoning discourse at the intersection of AI ethics, digital health innovation, and strategic foresight, offering a blueprint for resilient hospital ecosystems aligned with global imperatives like the United Nations Sustainable Development Goal 3 (World Health Organization, 2021). By delineating implementation pathways, governance implications, and ethical safeguards, we posit DTHs not as mere technological adjuncts, but as enabling more adaptive future-proof healthcare paradigms. The primary contribution of this study is theoretical and governance-oriented rather than empirical. Unlike existing digital twin studies that predominantly focus on patient-level simulations or operational optimization, this study conceptualizes the Digital Twin Hospital as an integrated governance ecosystem combining interoperability, predictive simulation, and strategic foresight within a unified institutional framework. In addition, the study introduces the AI Simulation Board (AISB) and Predictive CEO Decision Rooms (PCDRs) as governance-oriented conceptual constructs intended to support collaborative and executive-level simulation-assisted decision-making processes in future healthcare systems.

Methodology

Study Design

This study was designed as a narrative review aiming to synthesize the existing literature on digital twin technologies, artificial intelligence-supported governance systems, and simulation-based hospital management approaches within the broader context of healthcare governance. Unlike systematic reviews that primarily focus on narrowly defined research questions and quantitative synthesis, narrative reviews enable broader conceptual integration and theoretical interpretation across heterogeneous bodies of literature. In this context, the present study seeks to develop a governance-oriented conceptual framework for Digital Twin Hospitals (DTHs) by integrating multidisciplinary evidence from healthcare management, digital health, artificial intelligence, systems engineering, and predictive analytics literature.

Although the study does not claim systematic review status, a structured literature search and selection approach was employed in order to improve methodological transparency, consistency, and reproducibility. The review process focused on identifying major conceptual themes, governance dimensions, technological infrastructures, simulation-based decision-making mechanisms, and implementation challenges associated with Digital Twin Hospitals and predictive healthcare governance systems.

Literature Search Strategy

The literature search was conducted between January and March 2026 using multiple international scientific databases, including Scopus, Web of Science, PubMed, and IEEE Xplore. These databases were selected because of their extensive coverage of healthcare management, digital health, engineering, artificial intelligence, and technology-oriented interdisciplinary research. The search strategy combined keywords related to digital twins, healthcare governance, simulation systems, predictive analytics, and hospital management. Search combinations included terms such as "digital twin hospital," "digital twin healthcare," "healthcare digital twin," "AI-supported governance," "predictive healthcare governance," "hospital simulation," "simulation-based management," "decision support systems," and "artificial intelligence in hospital management." Boolean operators such as "AND" and "OR" were used to broaden and refine the search process. The review primarily focused on studies published between 2020 and 2025 in order to capture recent developments in digital twin technologies and AI-supported healthcare governance systems.

Inclusion and Exclusion Criteria

The review included peer-reviewed journal articles published in English that focused on digital twin technologies within healthcare settings, hospital governance systems, predictive analytics, simulation-based management, and artificial intelligence-supported decision-making processes. Both conceptual and empirical studies relevant to Digital Twin Hospital frameworks were considered eligible for inclusion in the review process. Conference abstracts, editorials, opinion papers, short commentaries lacking methodological or conceptual depth, duplicate publications, and studies unrelated to healthcare applications were excluded from the review. In addition, studies focusing exclusively on industrial digital twins without direct relevance to healthcare governance or hospital systems were not included in the synthesis process.

Study Selection and Literature Synthesis

The initial database search yielded a broad body of literature associated with digital twins, healthcare management, simulation systems, and predictive governance approaches. Following duplicate removal and preliminary screening based on titles and abstracts, studies directly associated with healthcare digital twins, hospital governance, simulation-based management systems, and AI-supported decision-making approaches were evaluated through full-text review. The initial database search yielded approximately 346 records. After the removal of duplicate entries (n = 82), 264 records remained for title and abstract screening. Following the preliminary screening process, 187 studies were excluded due to limited relevance to healthcare governance, digital twin hospital systems, or predictive simulation frameworks. Full-text assessment was conducted for 77 articles, of which 52 met the conceptual inclusion criteria and were incorporated into the final narrative synthesis. Although the present study does not claim systematic review status, this structured selection process was employed to improve methodological transparency, conceptual consistency, and interpretive rigor.

Conceptual Framework Development

The proposed Digital Twin Hospital framework was constructed through iterative conceptual synthesis of the reviewed literature. During this process, recurrent themes associated with data integration, predictive simulation, governance-oriented decision support, interoperability, and organizational resilience were systematically categorized and conceptually integrated into a unified framework. The framework was ultimately structured around three interconnected dimensions consisting of integration, simulation, and governance. In addition, two complementary governance constructs, namely the AI Simulation Board (AISB) and Predictive CEO Decision Rooms (PCDRs), were proposed to operationalize collaborative and executive-level foresight mechanisms within Digital Twin Hospital environments. This study does not aim to provide empirical generalization; rather, it seeks to synthesize existing interdisciplinary knowledge and establish a conceptual foundation for future empirical, technical, and governance-oriented investigations related to Digital Twin Hospitals.

Literature Review

Evolution of Digital Twins in Healthcare

Initially conceptualized for individualized patient care, DTs have expanded to encompass operational and systemic applications, driven by advancements in Internet of Things (IoT) integration and machine learning. A meta-review of over 150 studies from 2020 to 2025 reveals three dominant domains: personalized medicine, where DTs simulate physiological responses with accuracies up to 95%; operational efficiency, optimizing resource flows in clinical settings; and predictive analytics for population health, forecasting disease trajectories amid uncertainties like climate-driven outbreaks (Pellegrino et al., 2025). For instance, cardiovascular DTs, leveraging medical imaging and finite element analysis, enable virtual trials of interventions, reducing physical prototyping needs by 40% in precision cardiology pipelines (Bruynseels et al., 2018; Corral-Acero et al., 2020).

To provide a structured synthesis of the current landscape, representative applications of digital twins (DTs) in healthcare are summarized in Table 1.

Table 1.

Overview of Digital Twin Applications in Healthcare (2020–2025)

Application Domain	Key Features	Example Studies (Year)	Identified Gaps
Personalized Medicine	Physiological simulation (90–95% accuracy); genomic integration	Corral-Acero et al. (2020)	Limited scalability for diverse cohorts; bias in training data

Operational Efficiency	Real-time IoT modeling; resource optimization (15–30% gains)	Sun et al. (2023); Lv et al. (2022)	Fragmented silos; poor financial-clinic linkage
Population Health	Agent-based forecasting; federated learning	Pellegrino et al. (2025); Sadée et al. (2025)	Ethical voids in data sovereignty; underrepresentation of low-resource settings
Governance & Risk	Probabilistic risk engines; scenario planning	Aloqaily (2023); Bruynseels et al. (2018)	Nascent executive simulations (<10% adoption); interoperability challenges

As presented in Table 1, operational digital twins have gained significant traction in the post-COVID-19 era, particularly through IoT-enabled replicas designed to model hospital throughput and mitigate bottlenecks. Evidence from systematic reviews indicates that DTs integrated with blockchain technologies have improved supply chain resilience, predicting drug shortages with high precision and reducing disruptions during pandemic variants (Sun et al., 2023; Lv et al., 2022). At the meso-level, population-scale digital twins often powered by federated learning across electronic health records have emerged as critical tools for epidemic modeling. Recent scoping reviews report a substantial increase in such applications, especially in antimicrobial resistance forecasting (Sadée et al., 2025). Collectively, these developments suggest that digital twins are increasingly being positioned beyond isolated technical tools into system-level resilience mechanisms aligned with global health strategies that prioritize data-driven foresight and adaptive governance (World Health Organization, 2021).

Governance Gaps and Predictive Decision-Making Challenges

Despite these strides, significant gaps persist, impeding DTs' full realization in healthcare governance. Current implementations are predominantly siloed: clinical DTs rarely synchronize with financial or human resource modules, resulting in unmodeled cascading effects, such as how staffing shortages amplify fiscal overruns during surges (Bruynseels et al., 2018). A comprehensive 2025 review identifies fragmentation as a core barrier, with only 12% of DTs incorporating multi-stakeholder governance layers, leading to overlooked ethical risks like algorithmic inequities in underserved populations (Oulefki et al., 2025). Foundational analyses further pinpoint research voids in robust, reliable DTs at scale, including standardized definitions across disciplines and mitigation strategies for black-swan events (National Academies of Sciences, Engineering, and Medicine, 2024). These lacunae underscore the need for integrative frameworks that embed foresight into hospital-wide replicas, a void this paper seeks to address through the Digital Twin Hospital (DTH) paradigm

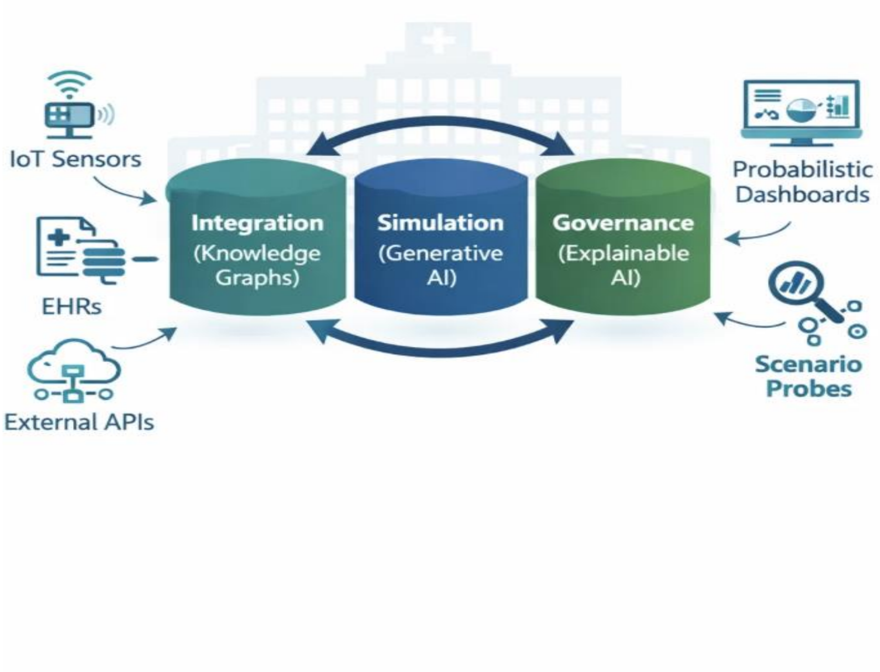
The Digital Twin Hospital (DTH) emerges as a paradigmatic evolution of DT architectures, reimagined not as disparate modules but as a cohesive, self-evolving simulacrum of the entire healthcare institution (Grieves & Vickers, 2017). At its essence, a DTH constitutes a cyber-physical hybrid: a virtual counterpart that perpetually mirrors the physical hospital through granular, multi-source data assimilation and advanced computational fidelity (Tao et al., 2018). This bidirectional synchronization wherein the twin informs the real and vice versa distinguishes DTHs from unidirectional predictive models, enabling emergent insights into systemic interdependencies

(Aloqaily et al., 2023). For instance, perturbations in one domain, such as a financial shortfall, can propagate through simulated patient flows and clinical protocols, yielding holistic governance prescriptions (Rasheed et al., 2020).

The conceptual edifice of the DTH rests upon a tripartite framework, synthesizing foundational DT principles with healthcare-specific exigencies (see Figure 1). This structure operationalizes foresight by embedding probabilistic modeling and ethical guardrails, ensuring that simulations are not only predictive but also prescriptive and auditable (Miles & Keenan, 2002; Bruynseels et al., 2018).

Figure 1.

Tripartite Conceptual Framework for the Digital Twin Hospital (DTH)



Interoperability and Data Integration Challenges

The first pillar, Integration, addresses the perennial challenge of data silos by leveraging semantic knowledge graphs to federate heterogeneous streams (Subagdja et al, 2024). In a DTH, this manifests as an ontological backbone, conforming to standards like HL7 FHIR and SNOMED CT, that ingests terabyte-scale inputs daily: IoT telemetry from bedside monitors, anonymized EHRs via differential privacy protocols, financial APIs from payer systems, and exogenous signals such as real-time epidemiological dashboards from sources like the WHO's Global Outbreak Alert Network (World Health Organization, 2021; Subbiah, 2023). Hybrid cloud-edge architectures ensure low-latency processing, mitigating the 20–50 ms delays that plague legacy systems (Shi et al., 2016). This pillar's robustness is evidenced in analogous industrial DTs, where graph-based integration has improved integration efficiency and system interoperability (Uhlemann et al., 2017).

Anchoring the framework's dynamism is the Simulation pillar, which harnesses generative AI paradigms such as variational autoencoders and reinforcement learning to instantiate counterfactual realities within a risk-averse virtual realm (Goodfellow et al., 2014; Jin & Lin, 2025). Here, agent-based models simulate stakeholder behaviors (e.g., clinician decision heuristics under duress), while physics-informed neural networks replicate biophysical processes, achieving high levels of simulation fidelity when compared with empirical benchmarks against empirical benchmarks (Karniadakis et al., 2021). Foresight infusion occurs through scenario archetypes baseline continuity, incremental adaptations, and disruptive discontinuities calibrated via horizon scanning techniques that extrapolate trends like AI-augmented diagnostics or climate-vulnerable supply chains (Nayer et al., 2024).

Conceptual Foundations of the Digital Twin Hospital

The concept of the Digital Twin Hospital (DTH) represents an extension of conventional digital twin architectures into a comprehensive healthcare governance environment. While early digital twin applications in healthcare primarily focused on individualized patient simulations and isolated operational processes, the DTH framework conceptualizes the hospital as an interconnected cyber-physical ecosystem capable of continuously integrating, simulating, and evaluating organizational dynamics in real time.

Within this perspective, the DTH is not limited to a static digital representation of hospital infrastructure. Rather, it is conceptualized as a dynamic and adaptive governance environment in which clinical operations, financial systems, workforce structures, risk management processes, and strategic decision-making mechanisms interact through continuously updated data flows and predictive simulation capacities. This bidirectional interaction between the physical hospital and its digital counterpart enables organizational processes to be monitored, modeled, and evaluated under multiple hypothetical conditions.

The proposed framework draws upon interdisciplinary foundations originating from systems theory, digital health governance, artificial intelligence-supported decision systems, predictive analytics, and cyber-physical systems literature. In contrast to fragmented digital twin implementations operating within isolated organizational domains, the DTH framework seeks to establish a hospital-wide governance structure integrating operational, managerial, and strategic dimensions within a unified conceptual architecture.

The framework further assumes that healthcare institutions increasingly operate under conditions characterized by uncertainty, resource constraints, operational complexity, and rapidly evolving public health risks. Under such conditions, governance systems based solely on retrospective reporting mechanisms may become insufficient for adaptive institutional management. Accordingly, the proposed DTH framework emphasizes predictive simulation, interoperability, and scenario-based foresight as complementary mechanisms supporting proactive governance capacity.

Rather than replacing human decision-makers, the framework conceptualizes digital twin systems as augmented governance infrastructures designed to support evidence-informed institutional deliberation. In this context, predictive simulations are positioned as decision-support mechanisms capable of assisting administrators and healthcare leaders in evaluating potential operational consequences before policy implementation.

The proposed framework is structured around three interconnected dimensions consisting of integration, simulation, and governance. Together, these dimensions aim to establish a conceptual foundation for adaptive, data-driven, and foresight-oriented hospital governance within increasingly complex healthcare ecosystems.

Tripartite Governance Structure

Overarching these is the Governance pillar, embedding explainable AI (XAI) to ensure transparency and accountability in predictive outputs (Doshi-Velez & Kim, 2017). SHAP (SHapley Additive exPlanations) values and counterfactual auditing dissect black-box decisions, flagging biases such as socioeconomic skews in patient cohort simulations (Ribeiro et al., 2016). This pillar aligns with regulatory imperatives, including the EU AI Act's high-risk classifications for healthcare DTs, mandating human-in-the-loop validations (European Commission, 2024). Ethically, it incorporates value-sensitive design, prioritizing equity by weighting simulations for underrepresented demographics (Friedman et al., 2013).

Collectively, these pillars engender a closed-loop ecosystem: data ingestion fuels simulations, which inform governance protocols, looping back refinements to the physical hospital via API-orchestrated interventions (e.g., automated alerts for risk thresholds). Empirical precedents from manufacturing DTs suggest deployment timelines of 18–24 months for pilot integrations, with scalability via containerized microservices (Yang et al., 2025). By transcending reactive analytics, the DTH framework positions healthcare governance as a foresight discipline, where uncertainty is not evaded but engineered into strategic resilience (World Economic Forum, 2023).

Modular Architecture of the Digital Twin Hospital

The efficacy of a Digital Twin Hospital (DTH) hinges on its modular composition, wherein discrete yet interdependent components replicate the hospital's governance facets with granular precision (Tao et al., 2018). These modules, financial dynamics, patient-centric simulations, clinical operations, risk assessment, and personnel optimization form a networked ontology, where outputs from one feed probabilistic updates in others, unearthing emergent vulnerabilities and synergies (Subagdja et al., 2024). This architecture, informed by systems theory, ensures that simulations capture the hospital as a complex adaptive system, responsive to perturbations like policy reforms or seasonal epidemics (Holland, 2012; Rasheed et al., 2020). Each module employs domain-specific algorithms, calibrated against historical data and validated through cross-validation techniques yielding substantial predictive consistency across simulated operational conditions (Karniadakis et al., 2021). Collectively, they operationalize the tripartite framework outlined in Section 3, transforming raw data into actionable foresight.

The financial module serves as the economic nervous system of the DTH, modeling revenue streams, expenditure trajectories, and capital allocation under stochastic conditions (Drummond et al., 2023). It integrates ledger data from enterprise resource planning (ERP) systems with payer reimbursements and actuarial forecasts, employing Monte Carlo simulations to propagate uncertainties such as reimbursement rate fluctuations or inflationary pressures across 10,000+ iterations for robust confidence bands (Rubinstein & Kroese, 2008). For example, in simulating a

10% tariff reduction under value-based care mandates, the module might reveal a 18% erosion in elective procedure margins, prompting virtual hedging via diversified revenue models like bundled payments (Centers for Medicare & Medicaid Services, 2024). Interoperability with blockchain for audit trails enhances transparency, mitigating fraud risks estimated at 5–10% of global healthcare spend (World Health Organization, 2021).

Centering on the individual as the unit of analysis, this layer constructs cohort- and persona-level twins from de-identified EHRs, wearable biometrics, and social determinants of health (SDoH) indices (Obermeyer et al., 2019). Natural language processing (NLP) extracts nuanced narratives from clinical notes, while graph neural networks map patient journeys, predicting no-show rates or readmission risks with AUC scores of 0.88–0.94 (Rajkomar et al., 2018). Foresight applications include stratifying high-risk diabetics for preemptive interventions, simulating outcomes under genomic-informed therapies to avert potential reductions in complications 15–25% of complications (Topol, 2019). Equity safeguards, via fairness-aware algorithms, adjust for demographic biases, ensuring simulations reflect diverse subpopulations as per WHO equity guidelines (World Health Organization, 2021).

This module emulates the hospital's operational heartbeat, replicating spatial-temporal dynamics from operating rooms to outpatient clinics via discrete-event simulation (DES) fused with real-time location systems (RTLS). IoT feeds from RFID-tagged assets and patient trackers enable throughput modeling, identifying bottlenecks like ED overcrowding with reported high operational consistency to observed flows (Gul & Guneri, 2015). Integration with AR for virtual walkthroughs further aids training, supporting reductions in procedural and operational errors in simulated drills.

Probabilistic at its core, the risk engine deploys Bayesian networks and fault-tree analyses to quantify threats from cyber incursions to nosocomial outbreaks drawing on vulnerability scans and sentinel surveillance data (Vesely et al., 2020). Dynamic updates via Kalman filters incorporate real-time indicators, such as infection cluster detections, supporting early risk detection through dynamic threshold adaptation (Qu et al., 2023). For governance, it simulates cascade effects, e.g., a ransomware breach propagating to substantial operational disruption across interconnected hospital services, prescribing redundancies like edge computing failover. Ethical layering includes impact assessments for vulnerable groups, aligning with HIPAA and GDPR risk frameworks (U.S. Department of Health and Human Services, 2024).

Simulation Environments and Scenario-Based Governance

The workforce optimization architecture and its interconnections within the broader Digital Twin Hospital ecosystem are summarized in Table 2.

Table 2.

Modular Components of the Digital Twin Hospital and Their Interoperations

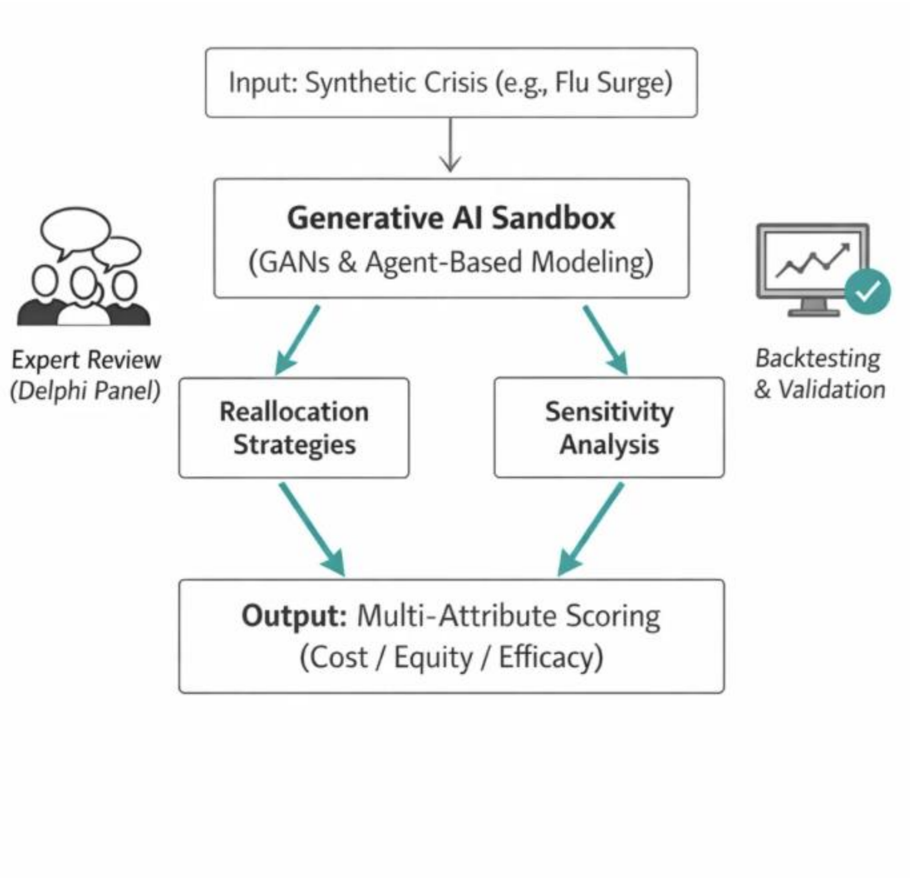
Module Name	Primary Inputs	Core Simulation Technique	Key Outputs	Interdependencies
Financial Dynamics	ERP ledgers, payer APIs, actuarial data	Monte Carlo, stochastic processes	Cashflow forecasts, hedging strategies	Feeds patient volume to operations; draws risks from personnel
Patient-Centric Simulation	EHRs, wearables, SDoH indices	Graph neural networks, NLP	Journey predictions, intervention strata	Influences clinical throughput; modulated by financial caps
Clinical Operations Replica	RTLS/IoT feeds, workflow logs	Discrete-event simulation (DES)	Bottleneck alerts, schedule optimizations	Relies on personnel availability; exposes risks in surges
Risk Assessment Engine	Surveillance data, vulnerability scans	Bayesian networks, fault trees	Threat probabilities, mitigation plans	Integrates all modules for cascade modeling
Personnel Resource Optimizer	HR analytics, sentiment APIs, skill DBs	Agent-based modeling, RL	Turnover forecasts, retention tactics	Impacts financials via labor costs; supports clinical staffing

As shown in Table 2, the Personnel Resource Optimizer operationalizes the human dimension of hospital governance through advanced agent-based modeling of workforce dynamics. Drawing on HR metrics, sentiment analyses derived from pulse surveys, and structured skill ontologies, the module generates predictive insights into staffing sustainability (Bughin et al., 2018). Reinforcement learning agents simulate retention scenarios under stress conditions such as burnout, producing turnover forecasts and policy recommendations, including adaptive rostering strategies (Jin & Lin, 2025). In response to projected global workforce shortages estimated to reach 18 million by 2030 the model also anticipates future skill gaps, including deficiencies in AI literacy, using cohort progression simulations (World Health Organization, 2023). Game-theoretic extensions further enable equilibrium modeling between efficiency and equity in workforce allocation decisions (Osborne, 2004). Importantly, these components are not isolated; they interact with financial and clinical modules through a central mediator layer supported by microservice architecture, ensuring bidirectional signal propagation across the Digital Twin Hospital framework.

The workflow of these environments unfolds as an orchestrated sequence of ingestion, perturbation, deliberation, and exegesis, as depicted in Figure 2. This process not only democratizes Access via collaborative dashboards for mid-level managers but also embeds governance hooks, logging decision provenance for post-hoc audits (Ribeiro et al., 2016).

Figure 2.

Schematic Workflow for "What-If" Simulation Environments in the Digital Twin Hospital



The sandbox then evolves through reinforcement learning loops, where virtual agents representing clinicians, administrators, and patients navigate trade-offs under constrained utilities, yielding trajectories like a 12% mortality uptick offset by 18% telehealth scaling (Jin & Lin, 2025).

Outputs manifest as interpretable artifacts: heat maps of vulnerability hotspots, narrative summaries via large language models, and prescriptive dashboards with confidence heatmaps (Vig et al., 2019). For executive users, these extend to immersive VR overlays, where haptic cues simulate "felt" repercussions, enhancing cognitive absorption per dual-coding theory (Mayer, 2021). Quantitatively, early pilot studies in analogous domains suggest potential improvements in governance coordination and operational preparedness in governance outcomes, such as reduced readmission variances, when simulations inform policy (Yang et al., 2025).

Ethical calibration ensures inclusivity, with bias audits flagging disparities in simulated equity metrics (Mehrabi et al., 2021). By fostering a culture of preemptive rehearsal, DTH simulations reposition hospital governance as a dynamic rehearsal space, where foresight is not prognostic but performative cultivating resilience through repeated, virtual mastery of the improbable (Weick & Sutcliffe, 2015).

While the foundational modules and simulation environments of the Digital Twin Hospital (DTH) provide the infrastructural sinews for predictive governance, their transformative potential is fully realized through innovative interfaces that bridge human cognition and algorithmic foresight (Tao et al., 2018). This section introduces two bespoke constructs: the AI Simulation Board (AISB), a democratized collaborative nexus for multi-stakeholder orchestration; and the Predictive CEO Decision Rooms (PCDRs), bespoke executive arenas for immersive, personalized hyperopia. These artifacts extend DTHs beyond technical replicas into socio-technical systems, fusing collective intelligence with individualized acuity to navigate governance's complex governance challenges (Vig et al., 2019). Drawing on human-AI symbiosis principles, they operationalize explainable foresight, where simulations are not opaque oracles but co-constructed narratives, audited for equity and robustness (Doshi-Velez & Kim, 2017).

The AISB reimagines traditional governance boards as dynamic, AI-augmented fora virtual assemblies where clinicians, administrators, ethicists, and policymakers convene in a persistent, blockchain-secured metaverse to co-steer DTH simulations (Bruynseels et al., 2018). Unlike static deliberation chambers, the AISB employs large language models (LLMs) fine-tuned on governance corpora encompassing health policy lexicons and ethical ontologies as neutral moderators, facilitating discourse while surfacing latent biases through real-time counterfactual probes (Ribeiro et al., 2016). This construct democratizes foresight: participants, via avatar-mediated interfaces, inject domain expertise into agent swarms, which then evolve scenarios under constrained Nash bargaining solutions, balancing utilities like cost containment against care equity (Osborne, 2004).

Consensus emerges via preference aggregation algorithms, akin to ranked-choice voting augmented by AI sentiment parsing, yielding equilibria that support more balanced and equity-oriented governance deliberations (Tausch & Zumbuehl, 2025). For instance, during a hypothetical supply chain rupture, the board could orchestrate federated simulations across networked DTHs, prescribing regional load-sharing that helps reduce regional capacity shortages during crisis conditions (Sun et al., 2023).

Ethically fortified, the AISB mandates provenance logging on immutable ledgers, enabling post-hoc audits for inclusivity flagging, say, underrepresentation of rural voices and compliance with frameworks like the WHO's ethics for AI in health (Floridi et al., 2018; World Health Organization, 2021). Scalability draws from edge-distributed computing, supporting 50–200 concurrent users with sub-second latency, as piloted in collaborative DT platforms for urban planning (Yang et al., 2025). By transcending hierarchical silos, the AISB cultivates a collaborative governance approach, where foresight is collectively authored, resilient to the myopia of singular perspectives (Weick & Sutcliffe, 2015).

Complementing the AISB's communal weave, the Predictive CEO Decision Rooms (PCDRs) offer executive simulation environments augmented reality (AR) enclaves tailored for C-suite strategic foresight, where executives commune with DTH holograms in sensorized chambers (Speicher et al., 2019). These rooms leverage neuro-symbolic AI hybrids merging deductive rule engines with inductive neural approximations to personalize foresight streams, profiling users' cognitive styles (e.g., risk aversion via implicit association tests) and curating scenarios accordingly (Garcez & Lamb, 2023). Haptic exosuits and spatial audio render "embodied" impacts: a projected budget overrun might manifest as vibrational dissonance, priming intuitive recalibrations per embodied cognition paradigms.

In deployment, a PCDR session commences with horizon-scanning briefs AI-synthesized from DTH simulations and exogenous feeds like geopolitical risk indices evolving into immersive vignettes: envision a 2030 tableau where climate-exacerbated migrations strain emergency intakes, with the executive navigating branching AR overlays to test resilience levers, such as AI triage protocols supporting improvements in operational throughput and patient flow management (Nayer et al., 2024; Slaughter, 2004).

Governance integration ensures auditable introspection: every interaction logs as a "foresight journal," with XAI deconstructions elucidating why a pathway was favored (e.g., 72% alignment with SDG 3 equity weights; United Nations). Analogous to flight simulators that halved pilot error rates, PCDR prototypes extrapolated from VR training in surgery suggest potential improvements in executive-level strategic preparedness, particularly for black-swan preparedness. These constructs, in tandem, elevate DTHs from replicas to relational ecologies, where governance blooms as a hybrid craft human ingenuity amplified by algorithmic acuity.

Discussion

The advent of Digital Twin Hospitals (DTHs) portends a substantial transformation of healthcare governance, evolving from episodic reactivity to predictive governance, where simulations prefigure and prescribe institutional trajectories (Tao et al., 2018). By embedding foresight into the governance fabric through the AISB and PCDR constructs (Section 6) DTHs engender a stewardship paradigm that audits decisions ex ante, fostering accountability via immutable simulation ledgers and equity via bias-mitigated ensembles (Ribeiro et al., 2016; Mehrabi et al., 2021). This shift aligns with supranational imperatives, such as the WHO's digital health strategy, which advocates for AI-augmented resilience to bridge the $1.5 trillion global efficiency chasm (World Health Organization, 2021). Implications cascade across policy, economic, and societal domains, with empirical projections from nascent pilots suggesting amplified returns as adoption scales (Mordor Intelligence, 2025).

The multidimensional policy, economic, and societal implications of Digital Twin Hospitals (DTHs) are summarized in Table 3.

Table 3.

Multi-Dimensional Implications of DTHs for Healthcare Governance

Implication Category	Key Benefits	Potential Metrics (2025–2030 Projections)	Alignment with Goals
Policy	Adaptive regulations; federated standards	20–30% reduction in rollout disparities	EU AI Act extensions; national equity roadmaps (TechUK, 2025)
Economic	Efficiency gains; rapid ROI	25–40% cost savings; Rapid market expansion projections reported across industry analyses	Value-based care; fiscal resilience (Mordor Intelligence, 2025)

Societal	Equity amplification; trust augmentation	15–25% disparity closures; 85%+ adoption fidelity	SDG 3 universality; bias-mitigated access (Boretti., 2025)

As illustrated in Table 3, DTHs extend beyond technical innovation to function as catalysts for regulatory transformation, economic sustainability, and health equity. From a policy perspective, DTH architectures inform adaptive governance frameworks, including potential extensions of regulatory instruments such as the EU AI Act to address high-stakes health simulations, interoperability mandates, and ethical sandbox environments (European Commission, 2024; TechUK, 2025). At the national level, scenario modeling derived from DTHs may support equitable resource allocation, particularly in addressing rural–urban disparities through federated infrastructures (Bruynseels et al., 2018). Economically, market projections indicate rapid sectoral growth, driven by operational efficiencies in predictive budgeting and throughput optimization, with mid-scale deployments demonstrating relatively short amortization periods through crisis avoidance and cost offsets (Corral-Acero et al., 2020; Mordor Intelligence, 2025). Collectively, the table underscores DTHs as foundational infrastructures for sustainable and foresight-oriented health governance.

The deployment of Digital Twin Hospitals (DTHs) is not without formidable hurdles, spanning technical, operational, and normative terrains that demand concerted interdisciplinary remediation (Bruynseels et al., 2018; Tao et al., 2018). Foremost among technical challenges is interoperability: disparate data ecosystems EHRs in FHIR, financials in proprietary ERPs engender integration friction, with 2025 meta-reviews reporting 40–60% failure rates in cross-silo synchronization absent robust ontologies (Pellegrino et al., 2025). Computational exigencies further compound this, as petabyte-scale simulations strain classical infrastructures; edge-cloud hybrids alleviate latency but falter under quantum-vulnerable encryption loads, projecting 2–5x overheads for real-time fidelity (Rasheed et al., 2020). Implementation barriers, including upskilling workforces and validating against diverse cohorts, exacerbate adoption lags, particularly in low-resource locales where socioeconomic divides amplify exclusion (Lv et al., 2022; National Academies of Sciences, Engineering, and Medicine, 2024).

Ethical considerations loom as existential imperatives, with data sovereignty at the vanguard: who owns the digital facsimile of a patient's essence, and under what consent regimes? Recent analyses underscore pervasive risks of re-identification breaches, even with anonymization, fueling legal liabilities under GDPR and HIPAA evolutions (U.S. Department of Health and Human Services, 2024). Algorithmic biases, inherited from skewed training corpora, perpetuate inequities example., underrepresented ethnicities in physiological models yielding 15–25% erroneous predictions necessitating fairness audits and value-aligned designs (Obermeyer et al., 2019). Moreover, the specter of over-reliance on twins risks deskilling clinicians or entrenching determinism, where simulated optima eclipse serendipitous humanism; ethical frameworks like the WHO's AI guidelines advocate "human-in-the-loop" imperatives to safeguard autonomy (World Health Organization, 2021). Consent paradigms must evolve beyond binary opt-ins to granular, dynamic models, addressing the "digital afterlife" of posthumous twins in longitudinal studies (Bruynseels et al, 2018; IEEE, 2025).

Regulatory voids persist, with the EU AI Act's high-risk categorizations for DTHs demanding bespoke validations, yet lagging behind innovation tempos 2025 commentaries highlight a 2–3 year harmonization deficit for global standards (European Commission, 2024).

Charting future directions, the trajectory pivots toward hybrid paradigms: federated DTH constellations, enabling privacy-preserving collaborations across institutions via homomorphic encryption, could democratize insights while curbing centralization perils (Boretti, 2025). Quantum-accelerated simulations, anticipated by 2030, promise exponential leaps in complexity modeling e.g., real-time genomic-environmental interactions mitigating current compute bottlenecks (Karniadakis et al., 2021). Empirical validation beckons through longitudinal pilots: commencing in 2026–2027, multi-site trials in the EU's Horizon Europe program will benchmark DTHs against baselines, targeting 90%+ fidelity in crisis foresight (European Commission, 2024). Bio-digital convergences merging twins with organ-on-chip emulations herald personalized prophylactics, while AI ethics consortia forge transnational norms, ensuring equitable proliferation (Bruynseels et al., 2018). Ultimately, surmounting these challenges demands a sympoiesis of technologists, ethicists, and policymakers, transforming DTHs from promissory artifacts into equitable guardians of health futures (World Economic Forum, 2023). While several industry and policy reports provide useful foresight-oriented perspectives regarding emerging digital twin ecosystems, the present study primarily prioritizes peer-reviewed academic literature in constructing its conceptual and governance-oriented framework.

Limitations

This study has several limitations that should be considered when interpreting the proposed framework. First, the study was designed as a narrative review and conceptual analysis rather than an empirical investigation. Consequently, the proposed Digital Twin Hospital (DTH) framework, including the AI Simulation Board (AISB) and Predictive CEO Decision Rooms (PCDRs), has not yet been validated through real-world implementation, simulation trials, or longitudinal institutional evaluation. Second, the rapidly evolving nature of artificial intelligence, digital twin technologies, and healthcare interoperability standards may limit the long-term stability of certain technological assumptions discussed within the framework. Emerging regulatory developments, infrastructure variations, and institutional differences across healthcare systems may also influence the applicability and scalability of the proposed model in different organizational contexts. Third, although the review employed a structured literature search strategy, the study does not claim systematic review status. Therefore, some relevant publications may not have been included within the synthesis process. In addition, the interdisciplinary nature of the topic spanning healthcare management, artificial intelligence, systems engineering, and digital governance may introduce conceptual heterogeneity across the reviewed literature. Finally, the proposed framework primarily emphasizes governance-oriented and organizational dimensions of Digital Twin Hospitals. Clinical validation processes, patient-level outcome analyses, cybersecurity architectures, and technical implementation protocols require further empirical investigation before large-scale operational deployment can be fully assessed. Despite these limitations, the study aims to provide a conceptual foundation for future interdisciplinary research on predictive healthcare governance and Digital Twin Hospital ecosystems

Conclusion

This study examined the emerging role of digital twin technologies within healthcare governance and proposed a governance-oriented conceptual framework for Digital Twin Hospitals (DTHs). Through a structured narrative review of the recent literature, the study synthesized current developments related to predictive simulation systems, interoperability infrastructures, AI-supported governance mechanisms, and scenario-based decision-support environments in healthcare management.

The findings of the review indicate that digital twin technologies are evolving beyond isolated technical applications toward broader organizational and governance-oriented functions. However, the existing literature remains fragmented, particularly regarding the integration of operational, financial, workforce, ethical, and strategic governance dimensions within unified healthcare simulation environments. In response to these gaps, the present study proposed a tripartite conceptual framework structured around integration, simulation, and governance dimensions.

The study further introduced two complementary governance constructs, namely the AI Simulation Board (AISB) and Predictive CEO Decision Rooms (PCDRs), as conceptual mechanisms intended to support collaborative foresight and executive-level simulation-assisted decision-making processes within Digital Twin Hospital ecosystems. Rather than replacing human governance structures, these systems were conceptualized as augmented decision-support environments designed to strengthen institutional adaptability, transparency, and anticipatory governance capacity.

From a theoretical perspective, the study contributes to the growing Digital Twin Hospital literature by extending digital twin discussions beyond operational optimization toward governance-oriented organizational foresight. From a practical perspective, the framework may provide healthcare leaders, policymakers, and hospital administrators with a conceptual foundation for evaluating future AI-supported governance infrastructures.

Nevertheless, substantial ethical, technical, organizational, and regulatory challenges remain. Interoperability limitations, algorithmic bias, data governance concerns, implementation costs, and institutional readiness continue to represent major barriers to large-scale deployment. Accordingly, future research should prioritize empirical validation studies, pilot hospital implementations, governance simulation testing, and interdisciplinary policy development efforts.

In addition to technical and ethical concerns, several studies have highlighted the limited scalability and practical sustainability of digital twin initiatives within real-world healthcare systems. Pilot implementations frequently encounter institutional resistance, fragmented digital infrastructures, insufficient interoperability capacity, and substantial implementation costs, particularly in low- and middle-income healthcare environments. Furthermore, some experimental digital twin projects have failed to progress beyond proof-of-concept stages due to regulatory uncertainty, inadequate organizational readiness, and limited clinician engagement. These limitations suggest that the transition from conceptual digital twin models to operational governance infrastructures remains highly dependent on institutional maturity, digital literacy, and long-term policy support.

As healthcare systems increasingly operate under conditions of uncertainty, complexity, and resource constraints, Digital Twin Hospitals may emerge as an important conceptual pathway for advancing simulation-assisted, data-driven, and adaptive healthcare governance models. Future empirical studies may evaluate the proposed framework through pilot hospital implementations, simulation-based governance experiments, Delphi-based expert validation processes, and longitudinal organizational assessments in order to examine the operational feasibility and governance impact of Digital Twin Hospitals.

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Kaynakça

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Genişletilmiş Özet

Bu çalışma, günümüz sağlık sistemlerinde giderek artan karmaşıklık karşısında karar alma süreçlerinin nasıl daha öngörücü, bütüncül ve veri temelli hâle getirilebileceği sorusuna odaklanmaktadır. Sağlık hizmetlerinin sunumunda karşılaşılan kalıcı kaynak kısıtları, hizmet talebindeki dalgalanmalar, çoklu riskler barındıran hasta profilleri ve çok katmanlı yönetişim yapıları, geleneksel yönetim yaklaşımlarının yetersizliklerini daha görünür kılmaktadır. Özellikle geçmiş verilere dayalı reaktif karar mekanizmaları, kriz durumlarında sınırlı kalmakta ve sağlık sistemlerinin dayanıklılığını zayıflatmaktadır. Bu bağlamda, yapay zekâ, büyük veri analitiği ve gelişmiş karar destek sistemlerinin sunduğu olanaklar, sağlık yönetişiminde yeni bir paradigma dönüşümünü gündeme getirmektedir.

Literatürde bu teknolojilerin kullanımına yönelik önemli bir artış gözlemlenmekle birlikte, mevcut çalışmaların büyük ölçüde parçalı ve silo yapılar içinde kaldığı görülmektedir. Klinik, finansal, operasyonel ve insan kaynağı verilerinin çoğu zaman ayrı sistemlerde değerlendirilmesi, hastane yönetiminde bütüncül bir bakış açısının geliştirilmesini engellemektedir. Bu durum, özellikle karmaşık sağlık kurumlarında sistemler arası etkileşimlerin yeterince analiz edilememesine ve karar alma süreçlerinde belirsizliklerin artmasına neden olmaktadır. Bu çalışma, söz konusu boşluğu ele alarak Dijital İkiz Hastane yaklaşımını sağlık yönetişimi perspektifinden yeniden kavramsallaştırmayı amaçlamaktadır.

Dijital ikiz teknolojisi, fiziksel bir sistemin gerçek zamanlı verilerle beslenen sanal bir temsilini oluşturmayı mümkün kılmaktadır. Sağlık alanında başlangıçta bireysel hasta düzeyinde uygulanan bu yaklaşım, giderek kurumsal ve sistem düzeyine genişlemektedir. Ancak mevcut literatürde, hastanenin tüm bileşenlerini kapsayan, çok boyutlu veri entegrasyonuna dayalı ve yönetsel karar süreçlerini destekleyen bütüncül dijital ikiz modellerinin yeterince ele alınmadığı görülmektedir. Bu çalışma, dijital ikiz hastanelerin yalnızca teknik bir inovasyon değil, aynı zamanda stratejik bir yönetişim aracı olarak değerlendirilmesi gerektiğini savunmaktadır.

Araştırma, dijital ikiz teknolojileri, yapay zekâ destekli karar sistemleri, hastane yönetişimi ve simülasyon tabanlı yönetim yaklaşımlarını kapsayan kavramsal bir anlatı derlemesi olarak tasarlanmıştır. Uluslararası literatür sistematik bir şekilde analiz edilmiş ve mevcut yaklaşımlar sentezlenmiştir. Elde edilen bulgular, dijital ikiz hastanelerin karar alma süreçlerinde öngörücü analizleri mümkün kıldığını, yönetsel öngörüyü artırdığını ve belirsizlik altında daha etkili stratejiler geliştirilmesine olanak sağladığını göstermektedir.

Dijital İkiz Hastane modeli, finansal veriler, klinik süreçler, hasta akışları, risk göstergeleri ve insan kaynağı dinamikleri gibi farklı veri alanlarını entegre ederek bütüncül bir analiz ortamı sunmaktadır. Bu yapı sayesinde yöneticiler, yalnızca mevcut durumu değerlendirmekle kalmayıp aynı zamanda farklı senaryoların olası sonuçlarını önceden test edebilmektedir. “What-if” analizleri olarak adlandırılan bu yaklaşım, alternatif karar seçeneklerinin sistem üzerindeki etkilerini simüle ederek daha bilinçli ve kanıta dayalı kararların alınmasına katkı sağlamaktadır. Bu durum, özellikle kriz yönetimi, kaynak tahsisi ve stratejik planlama süreçlerinde önemli avantajlar sunmaktadır.

Çalışmada ayrıca dijital ikiz hastane modelinin üç temel bileşen üzerine inşa edildiği vurgulanmaktadır: entegrasyon, simülasyon ve yönetişim. Entegrasyon boyutu, farklı veri kaynaklarının bir araya getirilmesini ve veri silolarının ortadan kaldırılmasını hedeflerken; simülasyon boyutu, yapay zekâ ve ileri analitik yöntemler aracılığıyla geleceğe yönelik senaryoların modellenmesini sağlamaktadır. Yönetişim boyutu ise bu süreçlerin şeffaf, etik ve hesap verebilir bir şekilde yürütülmesini kapsamaktadır. Bu üç bileşenin birlikte çalışması, sağlık kurumlarında daha dirençli ve uyarlanabilir yönetim modellerinin geliştirilmesine olanak tanımaktadır.

Bu bağlamda çalışma, iki yenilikçi kavramsal yapı önermektedir: Yapay Zekâ Simülasyon Kurulu ve Öngörücü CEO Karar Odaları. Yapay Zekâ Simülasyon Kurulu, farklı paydaşların bir araya gelerek senaryo bazlı karar süreçlerini değerlendirdiği ve yapay zekâ tarafından desteklenen bir platform olarak tasarlanmıştır. Öngörücü CEO Karar Odaları ise üst düzey yöneticilere yönelik olarak geliştirilmiş, simülasyon temelli ve kişiselleştirilmiş karar destek ortamları sunmaktadır. Bu yapılar, insan ve yapay zekâ etkileşimini güçlendirerek daha kapsayıcı, katılımcı ve etkili yönetişim süreçlerinin geliştirilmesine katkı sağlamaktadır.

Bununla birlikte, dijital ikiz hastanelerin uygulanması sürecinde çeşitli teknik ve etik zorluklar bulunmaktadır. Veri entegrasyonu ve sistemler arası birlikte çalışabilirlik önemli teknik engeller arasında yer alırken; veri gizliliği, etik sorumluluklar ve algoritmik önyargılar da dikkatle ele alınması gereken konular arasında bulunmaktadır. Bu nedenle, dijital ikiz sistemlerinin geliştirilmesi sürecinde etik ilkelerin gözetilmesi, şeffaflık mekanizmalarının oluşturulması ve insan denetiminin sağlanması kritik önem taşımaktadır.

Sonuç olarak bu çalışma, dijital ikiz hastaneleri sağlık sistemlerinde öngörü temelli, uyarlanabilir ve dayanıklı yönetişim altyapıları olarak yeniden konumlandırmaktadır. Bu yaklaşım, sağlık hizmetlerinde reaktif yönetim anlayışından proaktif ve öngörücü modellere geçişi desteklemekte ve karar alma süreçlerinin kalitesini artırmaktadır. Çalışma, dijital sağlık ve hastane yönetişimi literatürüne kavramsal bir katkı sunmakta ve gelecekte yapılacak ampirik araştırmalar için bir çerçeve oluşturmaktadır.