

Digital Twins in Information Systems: Virtual Simulations for Real-Time Decision-Making

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ABSTRACT

Digital twin technology has emerged as a transformative paradigm in information systems (IS), enabling real-time virtual simulation of physical processes to support adaptive decision-making. This study presents a systematic literature review of 25 peer-reviewed articles published between 2021 and 2025, examining how digital twins integrate with IS architectures, simulation engines, and AI-driven analytics to produce actionable insights in real time. The review covers applications in manufacturing, healthcare, transportation, agriculture, enterprise business intelligence, and library information systems. Key findings indicate that digital twins provide significant advantages in decision-making speed, predictive accuracy, and system optimization, though challenges remain in data interoperability, model validation, computational cost, and cybersecurity. The proposed research framework maps the end-to-end flow from physical data acquisition through digital twin simulation to real-time decision support, providing a conceptual foundation for future implementations. This paper contributes a structured overview of the state of the art and identifies priority areas for continued research and practice

Kata kunci: *Digital Twin; Information Systems; Real-Time Decision-Making; Virtual Simulation; AI; Industry 4.0; Systematic Literature Review.*

INTRODUCTION

The concept of digital twins virtual replicas of physical entities that are continuously updated with real-world data has evolved from aerospace engineering origins into a central technology in modern information systems. Originally conceptualized in the context of NASA's early space missions and later formalized in manufacturing contexts by Grieves, digital twins have since expanded into virtually every domain of enterprise computing. The growing convergence of the Internet of Things (IoT), big data analytics, artificial intelligence, and cloud computing has made it technically feasible and economically viable to construct, maintain, and query high-fidelity virtual models of complex systems in real time.

In the domain of information systems research, digital twins represent a significant shift in how organizations interact with their operational environments. Rather than relying on historical data or static predictive models, IS practitioners can now engage with live, dynamic simulations that reflect the current state of production lines, hospital workflows, urban traffic networks, and agricultural ecosystems. This shift from retrospective to prospective decision



support is particularly consequential in high-stakes, time-sensitive operational contexts where delays in information processing can result in quality loss, financial cost, or even physical harm.

Despite the growing body of literature, the field remains fragmented. Studies address digital twins from engineering, computer science, management information systems, and domain-specific perspectives – often without cross-disciplinary synthesis. The integration of digital twin architectures into formal IS frameworks, and specifically into decision-support systems (DSS), enterprise resource planning (ERP), and business intelligence (BI) platforms, is underexplored as a unified phenomenon. Furthermore, the role of simulation as an intermediary between raw sensor data and managerial decisions has not been systematically examined across multiple application domains.

This paper addresses this gap through a systematic literature review of recent empirical and conceptual contributions, synthesizing knowledge on digital twin architectures, simulation strategies, AI integration, and IS application outcomes. The objective is to provide researchers and practitioners with a comprehensive understanding of how digital twins enable real-time decision-making within information systems and to propose a coherent research framework that can guide future inquiry and implementation.

METHOD

Review Design and Search Protocol

This study employs a systematic literature review (SLR) methodology following established guidelines for IS research. The review protocol was designed to ensure transparency, reproducibility, and comprehensiveness in identifying and synthesizing relevant literature. Two electronic databases were searched: Scopus and Web of Science, supplemented by targeted searches in the IEEE Xplore Digital Library, SpringerLink, and Google Scholar for conference proceedings and specialized journal articles. The search was conducted in May 2026.

The primary search string combined terms relating to digital twins, information systems, simulation, and real-time decision-making. Boolean operators were applied as follows: ("digital twin" OR "digital twins") AND ("information system" OR "decision support" OR "real-time decision" OR "virtual simulation") AND ("enterprise" OR "IS" OR "ERP" OR "business intelligence" OR "simulation"). Language was restricted to English, and the publication period was limited to 2021–2026 to capture current developments in the field.

Inclusion and Exclusion Criteria

Studies were included if they: (1) focused on digital twin technology in the context of information systems, enterprise computing, or domain-specific IS applications; (2) addressed simulation, real-time data integration, or decision support; (3) were published in peer-reviewed journals or indexed conference proceedings; and (4) provided sufficient methodological or empirical detail to assess quality. Studies were excluded if they focused solely on hardware

engineering aspects of digital twins without IS relevance, were purely theoretical without any framework or case illustration, or lacked peer-review indexing.

Data Extraction and Synthesis

A total of 25 articles were retained after duplicate removal and quality screening. Data were extracted along the following dimensions: (1) publication year and venue; (2) digital twin architecture type; (3) simulation methodology; (4) IS integration context; (5) decision-making application; (6) AI or ML techniques employed; and (7) identified challenges. The extracted data were synthesized thematically, with a particular focus on cross-domain patterns and divergences.

Research Framework

Based on the reviewed literature, a research framework was developed to capture the essential functional components and information flows in a digital twin-enabled IS for real-time decision-making. The framework, illustrated in Figure 1 below, maps the journey from physical data acquisition through digital twin simulation, analytics, and IS integration, culminating in real-time decision support across multiple application domains. The framework draws on conceptual models proposed by Semeraro et al. (2021), Walton et al. (2024), and Abdoune et al. (2024), and extends them with domain-specific application layers identified from the broader review.

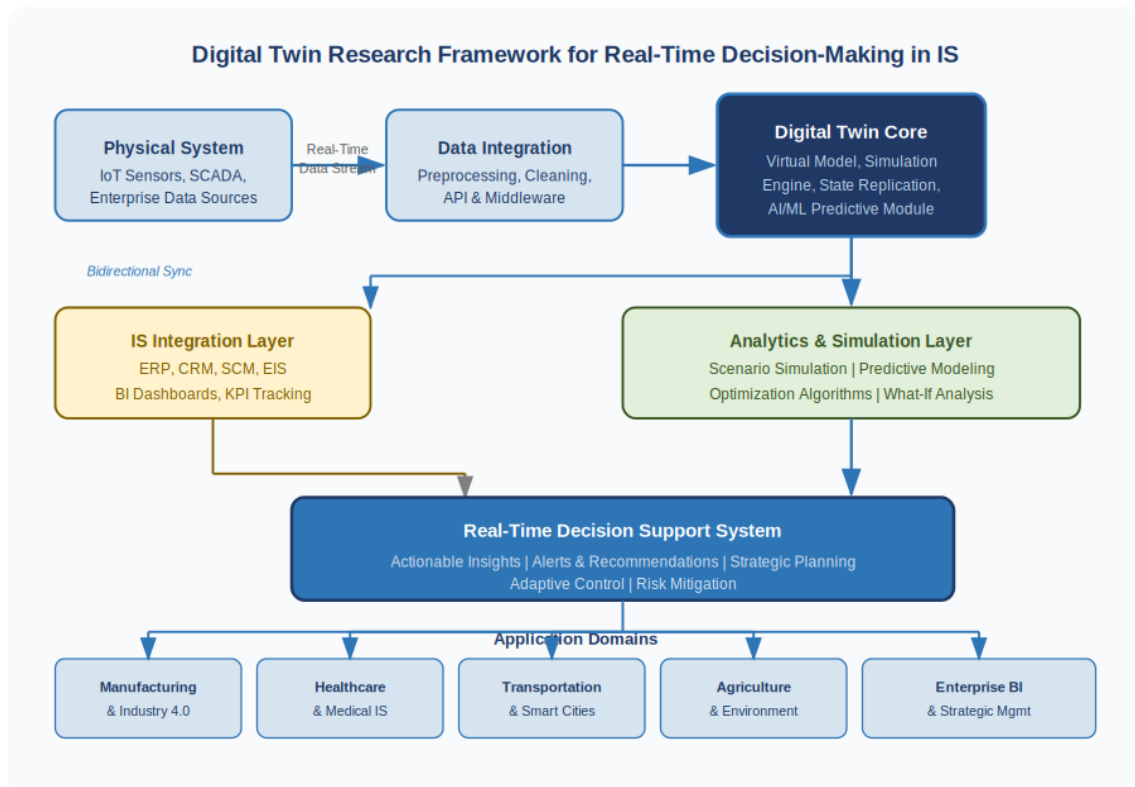


Figure 1. Research Framework: Digital Twin Architecture for Real-Time Decision-Making in Information Systems

RESULT AND DISCUSSION

Evolution and Architecture of Digital Twins in IS

The systematic review reveals that digital twin research in IS has accelerated substantially since 2021, with a notable surge in publications between 2024 and 2025. Semeraro et al. (2021) established an influential foundational framework, identifying the paradigm's core components: the physical entity, the virtual model, and the bidirectional data connection. This three-part architecture has since been refined and extended. Segovia and García (2022) elaborated on design and implementation dimensions, demonstrating how simulation fidelity improves proportionally with sensor density and communication bandwidth.

A key architectural distinction that emerged from the review is between static digital twins built from design specifications and updated periodically and dynamic, real-time digital twins that maintain continuous synchronization with live physical systems. The latter category, which is the focus of this review, has become increasingly feasible through advances in edge computing, 5G connectivity, and in-memory database technologies. Lopez (2021) proposed a real-time event-based platform that decouples simulation computation from data ingestion, allowing high-frequency sensor data to update virtual models without sacrificing simulation stability.

Lu et al. (2022) introduced the concept of a Cognitive Digital Twin, which extends the basic simulation paradigm with knowledge representation and autonomous reasoning capabilities. This cognitive layer enables the digital twin to not only mirror the physical system but also to infer causal relationships, anticipate failures, and recommend corrective actions effectively transitioning from a descriptive to a prescriptive analytics tool. This trajectory aligns with the broader IS literature on intelligent decision support systems.

Simulation Methods and AI Integration

The synthesis of simulation methodologies reveals two dominant paradigms: Discrete Event Simulation (DES) and Agent-Based Simulation (ABS). Santos et al. (2021) conducted a systematic review of DES and ABS in digital twin contexts, finding that DES is favored in manufacturing and logistics for its computational efficiency in modeling queue-based processes, while ABS offers superior adaptability in complex, emergent systems such as healthcare patient flows or traffic ecosystems. Hybrid approaches combining both methods are increasingly reported, particularly in smart factory applications.

AI and machine learning integration has emerged as a defining feature of second-generation digital twins. Xu, Çelik, and Chen (2022) demonstrated a real-

time optimization framework that couples a digital twin's simulation engine with predictive simulation learning, dynamically adjusting the model parameters based on observed discrepancies between simulated and actual states a form of online model calibration. Chen et al. (2025) extended this concept with a Model Predictive Control (MPC) approach using time-series deep neural networks, achieving sub-second decision cycles in additive manufacturing.

Chen, Tsai, and colleagues (2025) further advanced this direction with uncertainty-aware digital twins employing deep quantile learning for robust MPC under noisy, incomplete sensor streams – a critical capability for real-world IS deployments where data quality cannot be guaranteed. Monek and Fischer (2024) integrated a fuzzy-logic-based decision module directly into the digital twin, demonstrating that soft-computing approaches can complement neural methods in expert systems with interpretability requirements. Mikołajewska et al. (2025) highlighted generative AI's emerging role in digital twin fault diagnosis for predictive maintenance in Industry 4.0 and 5.0 contexts.

Information System Integration and Decision Support

Integration with enterprise information systems constitutes a central challenge and opportunity identified across the reviewed literature. Yan, Hong, and Warren (2021) demonstrated how digital twins, coupled with knowledge visualization techniques, could directly support executive decision-making through an enterprise digital twin platform that integrates with ERP and executive information systems. Their case study in strategic management decision support showed that digital twin-derived simulations reduced scenario analysis time by over 60 percent compared to conventional BI methods.

Puppala (2025) investigated the role of digital twins in AI-driven enterprise business intelligence, finding that scenario simulation and strategic planning capabilities were significantly enhanced when digital twin outputs were integrated with existing BI dashboards. The convergence of digital twin simulation data with KPI monitoring frameworks allowed managers to shift from lagging indicators to leading indicators of operational performance.

Mahankali (2025) proposed a detailed enterprise architecture framework for real-time manufacturing decision support, mapping digital twin data flows onto standard IS architecture patterns including service-oriented architecture (SOA) and microservices. This contribution is particularly significant for IS practitioners seeking to implement digital twins within existing IT governance structures. Štefko et al. (2025) extended this perspective to the industrial metaverse context, envisioning digital twin-based virtual factories as nodes

within broader cyber-physical production networks – a vision that reframes IS architecture at an ecosystem level.

Domain Applications

The review identifies five primary application domains for digital twins in IS, each with distinct decision-support requirements. In manufacturing and Industry 4.0, digital twins enable real-time process optimization, quality control, and predictive maintenance. Walton, Ciarallo, and Champagne (2024) proposed a unified digital twin framework integrating virtual, physical, and prescriptive analytical components to support adaptive real-time decision-making in complex production environments. Zenkovich (2025) demonstrated a digital twin-driven decision support approach for adaptive control of production systems at a conference on Smart Industry.

In healthcare, Vallée (2023) provided a comprehensive review of digital twin applications in health systems, identifying patient pathway simulation, resource allocation optimization, and pandemic preparedness modeling as primary decision-support use cases. The paper noted that data privacy regulations represent a particularly acute challenge in healthcare IS deployments. In transportation, Kušić, Schumann, and Ivanjko (2023) implemented a traffic digital twin that achieved real-time synchronization of motorway dynamics, demonstrating tangible improvements in incident response time and congestion prediction accuracy.

Agriculture and environmental monitoring represent a rapidly growing frontier. Peladarinos et al. (2023) reviewed digital twin implementations for smart agriculture, cataloging applications ranging from precision irrigation and crop disease detection to livestock monitoring. In ocean environmental monitoring, Papachristopoulou et al. (2025) developed the StreamHandler system – a real-time decision support platform integrated with a digital twin of the ocean for environmental data stream processing.

In library and information services, Jabborov et al. (2025) demonstrated the development of digital twins for library information system simulation, showing how virtual replicas of library resource flows could support decisions on cataloging, user service, and collection development. This application represents an important extension of digital twin concepts into traditionally non-industrial IS domains.

Challenges and Limitations

Despite the demonstrated potential, several cross-cutting challenges are consistently identified in the literature. Data interoperability and standardization remain primary barriers to scalable digital twin IS deployments: sensor protocols, data formats, and middleware specifications vary widely across vendors and domains, complicating real-time integration. Model validation and the verification of digital twin accuracy against physical system behavior is another persistent challenge; Bitencourt, Wooley, and Harris (2024) conducted a systematic review of validation methodologies for manufacturing digital twins, concluding that no consensus standard has yet emerged.

Computational resource requirements, particularly for high-fidelity AI-enhanced simulation at scale, impose infrastructure costs that may be prohibitive for small and medium enterprises. Cybersecurity presents a further systemic risk: the bidirectional data connections that make digital twins powerful also create attack surfaces that can compromise both virtual and physical systems. Zhang et al. (2022) proposed explainable human-in-the-loop mechanisms for dynamic data-driven digital twins, partially addressing the dual challenges of transparency and human oversight in automated IS decision loops. Marah and Challenger (2024) addressed hybrid reasoning approaches for agent-based digital twins of distributed robotic systems, highlighting the complexity of coordination in multi-agent physical-virtual environments.

Khan and Ahmad (2025) synthesized best practices for harnessing digital twins for optimized system performance and sustainable innovation, emphasizing that organizational readiness, change management, and skills development are as critical as technical infrastructure. Rainy et al. (2023) reinforced this perspective through a systematic review of AI-enhanced decision support tools in IS, finding that human factors including trust in automated recommendations and interpretability of AI outputs significantly moderate adoption and effectiveness outcomes

Table 1. Summary of Digital Twin Applications in Information Systems by Domain

Domain	Digital Twin Application	Decision Support Capability	Key Reference
Manufacturing	Production line monitoring & optimization	Real-time process control, downtime reduction	Mahankali (2025); Štefko et al. (2025)
Healthcare	Patient health state simulation	Clinical decision-making, resource allocation	Vallée (2023)

Transportation	Traffic flow virtualization	Dynamic routing, congestion mitigation	Kušić et al. (2023)
Agriculture	Crop and environment monitoring	Irrigation, fertilization decisions	Peladarinos et al. (2023)
Enterprise BI	Scenario simulation & planning	Strategic planning, KPI-based analytics	Puppala (2025); Yan et al. (2021)
Library / IS	Library system simulation	Resource management, user service optimization	Jaborov et al. (2025)

Source: Synthesized from systematic literature review (2021–2025)

CONCLUSION

This systematic literature review has examined 25 peer-reviewed contributions on digital twins in information systems, with a focus on virtual simulation for real-time decision-making. The findings confirm that digital twin technology has matured into a versatile and high-impact IS tool, with documented applications across manufacturing, healthcare, transportation, agriculture, enterprise business intelligence, library systems, and ocean environmental monitoring. The integration of AI including machine learning, deep neural networks, fuzzy logic, and generative AI with digital twin simulation engines represents the most consequential recent development, enabling not only descriptive and predictive capabilities but also prescriptive, adaptive decision support.

The research framework proposed in this paper provides a structured model of the end-to-end digital twin IS pipeline, from physical data acquisition and digital twin core simulation through analytics, IS integration, and domain-specific decision support. This framework is intended to serve as a conceptual anchor for researchers designing new digital twin IS architectures and for practitioners evaluating implementation pathways.

The review also surfaces a set of recurring challenges that the field must address to realize the full potential of digital twin IS: data standardization and interoperability, model validation methodology, computational scalability, cybersecurity, and human factors in AI-assisted decision-making. Future research should prioritize longitudinal empirical studies of digital twin IS in production environments, the development of domain-neutral validation standards, and the exploration of federated and privacy-preserving digital twin architectures for sectors with strict data governance requirements.

As digital twin technology continues to converge with emerging paradigms including the industrial metaverse, generative AI, autonomous agents, and quantum computing the role of IS researchers will be to ensure that these

powerful tools are designed, integrated, and governed in ways that are technically sound, organizationally effective, and aligned with broader societal values

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