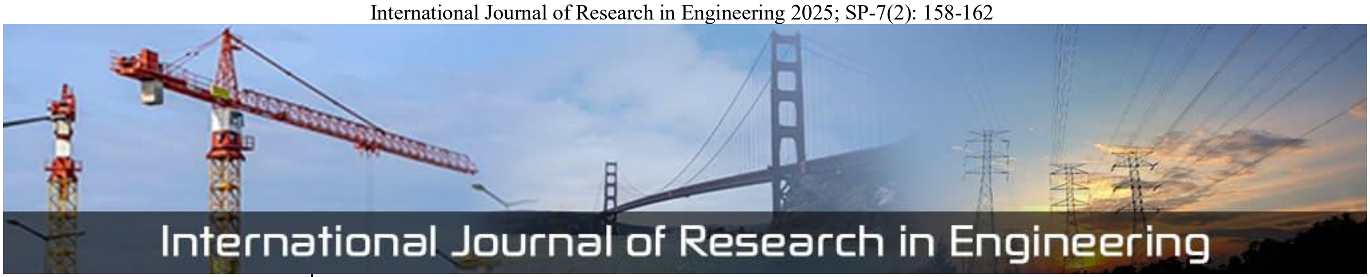
International Journal of Research in Engineering 2025; SP-7(2): 158-162



E-ISSN: 2664-8784
P-ISSN: 2664-8776
IJRE 2025; SP-7(2): 158-162

www.engineeringpaper.net
Received: 14-05-2025
Accepted: 16-06-2025

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Two-Days National Conference on Multidisciplinary Approaches for Innovation and Sustainability: Global solution for contemporary Challenges-NCMIS (DPG Degree College: 17 th-18th 2025)

Digital twin: A scoping review, challenges and open research

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DOI: https://www.doi.org/10.33545/26648776.2025.v7.i2c.104

Abstract
Digital Twin technology is an emerging concept that has become the center of attention for industry and, in more recent years, academia. A digital twin is a digital representation of objects, people, or processes, whether real or intended. Digital twins utilize real-time data, simulation, machine learning, and reasoning to simulate real situations, demonstrating possible outcomes so organizations can make better decisions. The Digital Twin is defined extensively but is best described as the effortless integration of data between a physical and virtual machine in either direction. The Digital Twin has the potential to give real-time status on machines performance as well as production line feedback. It gives the manufacturer the ability to predict issues sooner. Digital Twin use increases connectivity and feedback between devices, in turn, improving reliability and performance. AI algorithms coupled Digital Twins have the potential for greater accuracy as the machine can hold large amounts of data, needed for performance and prediction analysis. The Digital Twin is creating an environment to test products as well as a system that acts on real- time data, within a manufacturing setting this has the potential to be a hugely valuable asset. The challenges, applications, and enabling technologies for Artificial Intelligence, Internet of Things (IoT) and Digital Twins will be presented. This paper provides an assessment of the enabling technologies, challenges and open research for Digital Twins. The purpose of this paper is to do a literature review and explore how Digital Twins streamline intelligent automation in different industries. This paper defines the concept, highlights the evolution and development of Digital Twins, reviews its key enabling technologies, examines its trends and challenges, and explores its applications in different industries.

Keywords: Digital twins, digital twin technologies, digital twin drivers, healthcare and life sciences, automotive and aerospace industry, construction and real estate

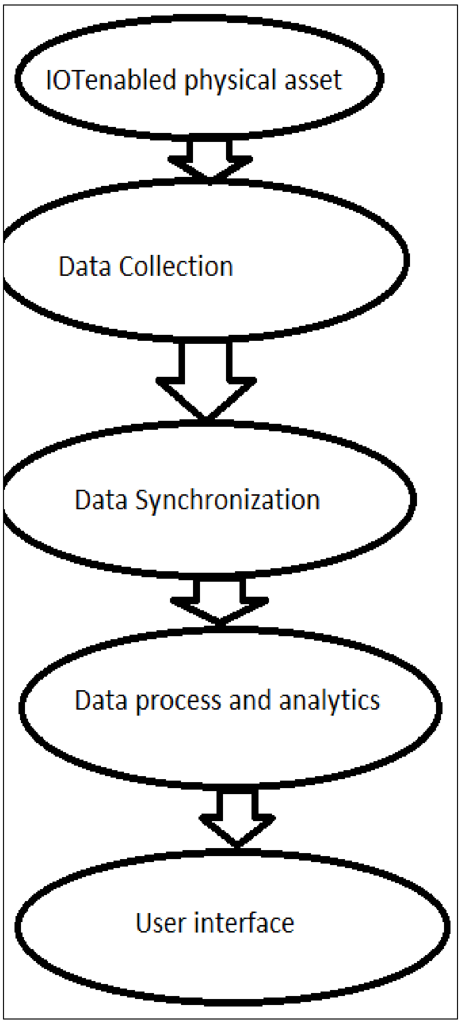
1. Introduction
A digital twin is a virtual representation of a physical product that is paired with that physical product over the course of life-cycle management to help it develop from a concept to a prototype to its final version. The term was coined by Michael Grieves and John Vickers in 2003; since then, the concept has been broadly accepted and applied in many fields, to the point that it was listed as a key strategic technology trend in 2019 by Gartner, a technology research and consulting company.* This development is largely driven by advances in technologies such as Internet-of-Things (IoT), multi- physical simulation, real-time sensors and sensor networks, machine learning, artificial intelligence, big data, data management, and data processing. This article is an introduction to the concept of digital twins.

1.1 Digital Twin Components
1.2 Hardware Components
Hardware components form the physical foundation of Digital Twins. These include sensors, actuators, devices, and computing infrastructure that capture and process real-world data, enabling the creation of a digital replica. Imagine an industrial robot arm on a manufacturing assembly line. The robot arm is equipped with various sensors, such as position sensors, temperature sensors, and force sensors. These sensors gather data about the robot's movements, the forces it applies, and the temperatures it operates in. These hardware components serve as the eyes and ears of the digital Twin, providing crucial data that reflects the real-world behavior of the robot arm.

2. Middleware Component
Middleware acts as the bridge between the hardware and software components, facilitating data communication, integration, and management. Middleware ensures that data from hardware sensors is collected, processed, and made accessible to software applications for analysis and simulation. In an automotive manufacturing setup, there are multiple robots, conveyors, and machines. Middleware solutions gather data from sensors attached to these devices and standardize the format for software consumption. It aggregates data like speed, position, and status, making it accessible to the Digital Twin's software component. This middleware layer plays a vital role in maintaining data consistency and ensuring that software applications receive accurate and relevant information.

3. Software Components
Software components are the brains of the Digital Twin. They use data from hardware sensors and middleware to create virtual representations, run simulations, and enable real-time analysis and decision-making. Consider an aircraft engine design process. Engineers create a Digital Twin of the engine, incorporating design specifications, material properties, and real-world data from hardware sensors placed on physical prototypes. Specialized software models simulate how different parts of the engine interact under various conditions, such as different altitudes and temperatures. These software components allow engineers to visualize stress points, identify potential failures, and optimize the engine's design before it's physically built.

4. Digital Twin Operation
The life of a digital twin begins with experts in applied mathematics or data science researching the physics and operational data of a physical object or system in order to develop a mathematical model that simulates the original. The developers who create digital twins ensure that the virtual computer model can receive feedback from sensors that gather data from the real world version. This lets the digital version mimic and simulate what is happening with the original version in real time, creating opportunities to gather insights into performance and any potential problems. A digital twin can be as complex or as simple as you require, with differing amounts of data determining how precisely the model simulates the real world physical version. The twin can be used with a prototype to offer feedback on the product as it is developed or can even act as a prototype in its own right to model what could occur with a physical version when built.

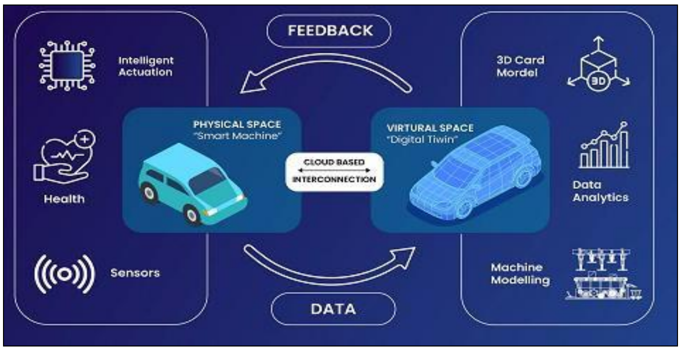


5. Digital Twin Algorithm
The DT was defined by Ivanov (2023) as a virtual system that comprises: "

1. A digital visualization of a physical supply chain and its elements (e.g. firms, flows, and products) in a computer model,
2. Digital technologies providing data about the physical object (e.g. sensors, blockchain, clouds), and

3. Descriptive, predictive and prescriptive analytics for decision-making support". The use of DT technology in production-distribution systems management can bring numerous benefits, such as increasing the operational efficiency of the system, improving its resilience and reducing costs.

In this problem, the DT model is designed with a twofold objective.
1. to identify potential disruptions that might cause delays in the delivery lead time; and
2. To periodically determine the optimal values of the replenishment parameters by considering the changing delivery lead times. Conforming to the definition of Ivanov (2023), the proposed DT consists of the Physical System (PS), which represents the real- world production-distribution processes, and the digital counterpart, denoted as Cyber System (CS), which is the virtual replica of the PS. In DT applications for production-distribution systems management, PS and CS interact through a bidirectional data flow by means of digital technologies (e.g., sensors or clouds). The physical system continuously generates the real data that are collected and processed by the CS. In this work, the CS consists of a combination of a simulation model, data analytics with the Moving Average (MA) technique, an Artificial Neural Network (ANN) as an ML model, and Particle Swarm Optimization (PSO) as a metaheuristic algorithm for the optimization procedure. Figure provides an overview of the proposed DT architecture, which is described in detail in the following subsections.



6. Digital Twin Applications

1. Predicting the performance of packaging materials product packaging can be virtualized and then tested for errors before being packaged. Digital twins help logistics companies determine material feasibility.
2. Enhancing shipment protection logistics companies can analyze how different packaging conditions can affect product delivery with the help of digital twins.
3. Optimizing warehouse design and operational performance Digital twins enable logistics companies to test warehouse layouts so companies can choose the most efficient warehouse design to maximize operational performance.
4. Creating a logistics network a digital twin of a road network carries information about the traffic situation, road layout, and construction. With that knowledge, logistics companies can design the distribution routes and inventory storage locations.
5. Construction a digital twin can help construction firms understand how a building is performing in real-time, which allows them to tweak performance to optimize efficiency. Data collected from digital twin can be used for planning and designing future buildings.
6. Healthcare it's been reported that 66% of healthcare executives expect increasing investment in digital twins over the next three years.2 Digital twins can help healthcare providers virtualize healthcare experience to optimize patient care, cost, and performance.

- Top use cases of digital twin of healthcare include.

7. Digital twin of a healthcare facility

Digital twin technology can be used to generate a virtual twin of a hospital to review operational strategies, capacities, staffing, and care models to identify areas of Improvement, predict future challenges, and optimize organizational strategies. Therefore, digital twins of hospitals can be used for generating facility replicas, and in turn this enables.

Resource optimization: Leveraging historical and real-time data of hospital operations and surrounding environment (e.g. COVID-19 cases, car crashes, etc.) To create digital twins enables hospital management to detect bed shortages, optimize staff schedules, and help operate rooms. Such information increases the efficiency of resources and optimized the hospital's and staff's performance, while decreasing costs. For example, a review study has shown that utilizing digital twins to manage the smooth coordination of several processes enabled a hospital to reduce the time in treatment of stroke patients by. Risk management: Digital twins provide a safe environment to test the changes in system performance (staff numbers, operation room vacancies, device maintenance, etc.) which enables implementing data-driven strategic decisions in a complex and sensitive environment.

8. Digital twin of the human body

Digital twins are also applied for modeling organs and single cells or an individual's genetic makeup, physiological characteristics, and lifestyle habits to create personalized medicine and treatment plans. These replicas of the human body's internal systems improve medical care and patient treatment by.

Personalized diagnosis: Digital twins allow collection and usage of vital data (e.g. blood pressure, oxygen levels, etc.) at the individual level which helps individuals to track persistent conditions and, consequently, their priorities and interactions with doctors by providing basic information.

Thus, such personalized data serve as the basis of clinical trials and research data at labs. By focusing on each individual separately, doctors do not derive treatments from large samples. Rather, they rely on customized simulations to track the reactions of each patient to different treatments, which increases the accuracy of the overall treatment plan. Despite the interest and increasing amount of efforts for personalized medicine, there are no digital twin's applications for actual patients. One of the centers specialized on personalized medicine is Linköping University in Sweden who mapped mice RNA into a digital twin to predict the effects of medication. Treatment Planning: With advanced modeling of the human body, doctors discover the pathology before the disorders are evident, experiment with treatments, and improve preparation for surgeries.

9. Digital twin of human body

Digital twins for medicine and device development

Digital twin in healthcare can improve the design, development, testing, and monitoring of new drugs and medical devices. For example:

- **Drugs:** Digital twins of drugs and chemical substances enable scientists to modify or Redesign drugs considering particle size and composition characteristics to improve delivery efficiency.
- **Devices:** A digital twins of a medical device enables developers to test the characteristics or uses of a device, make alterations in design or materials, and test the success or failure of the modifications in a virtual environment before manufacturing. This significantly reduces the costs of failures, and enhances the performance and safety of the final product.

10. Digital twin for medication

- **Manufacturing:** Applications of digital twins are most widely used in the manufacturing industry. Manufacturing relies on high-cost equipment that generates a high volume of data which facilitates creating digital twins. Digital twin applications in manufacturing are as follows.
- **Product development:** Digital twins can help engineers test the feasibility of upcoming products before launching. According to the test results, engineers start producing or shift their focus to creating a feasible product.
- **Design customization:** With digital twins, businesses can design various permutations of the product so that they can offer personalized products and services to their customers.
- **Shop floor performance improvement:** A digital twin can be used to monitor and analyze end-products and help engineers see which products are defected or has lower performance than intended.
- **Predictive maintenance:** Manufacturers leverage digital twins to predict potential downtimes of machines so that businesses minimize non-value adding maintenance activities and improve the overall efficiency of machines since technicians take action before a failure happens.

11. Aerospace

Before digital twins, physical twins were used in aerospace engineering. An example is Apollo 13 program in the 1970s where NASA scientists on earth were able to simulate the condition of the ship and find answers when critical issues arose. Later in 2002, the digital twin concept is introduced by John Vickers from NASA. Today the importance of digital twins in the aerospace industry is acknowledged by experts that 75% of air force executives have cast the vote of confidence in favor of the digital twin, according to Business Wire's survey report. With digital twins, engineers can use predictive analytics to foresee any future problem involving the airframes, engine, or other components to ensure the safety of the people onboard. Automotive developing new cars mostly takes place in virtual setting. Digital Twins are used in the automobile industry to create the virtual model of a connected vehicle. Automotive companies use the technology to design the ideal automotive product even before production starts. They simulate and analyze the production phase and the problems that might occur once the vehicle hits the roads.

12. Self-driving car development

Though digital twin practices can be used in the traditional automotive manufacturing industry, digital twins are handy for autonomous vehicle companies. Self-driving cars contain numerous sensors that collect data regarding the vehicle itself and the environment of the car. Due to the liability questions, creating a digital twin of an autonomous vehicle and testing it can help identify and minimize unexpected damage and injuries. Some applications of digital twins in the automotive industry are road testing and vehicle maintenance. For more on digital twin applications in manufacturing, feel free to watch the video of Dr. Norbert Gaus who is head of R&D in Automation and Digitalization at Siemens. He is explaining how digital twins help streamline the production process in the real world and providing examples: Retail

13. Customer modeling & simulations

Retailers can create digital twins of customer personas to improve the customer experience they deliver. For example, retailers can provide ideal fashion clothing products to customers based on their digital twin models. Today, businesses use digital twins in numerous ways from product development to operational performance improvement. The digital twin market is expected to grow to $73.5 billion by 2027, at a CAGR of 60.6%. 1 Increased digitization and IoT adoption are making it easier for businesses to build accurate digital twins and drive adoption of the technology.

14. Conclusion

Over the past twenty years, the digital twin has evolved from a product life-cycle management concept into a variety of well-developed technologies that benefit many industries through applications like intelligent asset performance management and operations optimization. Current applications of digital twins are replacing humans in the traditional human-machine model with a data-driven self-learning intelligent system. By leveraging machine learning, artificial intelligence, big data technologies, and advanced sensor technologies, digital twins will likely become key technology for many industries to increase system performance and operational optimization.

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