

DIGITALIZATION OF THE PLANT'S TECHNOLOGICAL MAP: THE INTERACTION BETWEEN DIGITAL TWIN AND AUTOMATION

Ergashev B.T.

*Senior lecturer at the department of "Technological Processes and Automation of
Production" at Bukhara state technical university.*

Ergasheva G.B.

*Assistant at the department of "Technological Processes and Automation of
Production" at Bukhara state technical university.*

Abstract: In today's fast-evolving industrial landscape, the digital transformation of manufacturing processes is becoming a critical driver of efficiency, flexibility, and innovation. One of the most promising developments in this area is the integration of digital twin technology with automation systems, which enables the creation of intelligent, real-time virtual replicas of physical assets and processes. These digital models not only mirror the actual state of the plant but also interact dynamically with automated systems to support continuous monitoring, predictive maintenance, and optimized control. Recent advancements have shown that this fusion can turn conventional technological maps—once static and manually updated—into living digital frameworks that enhance visibility and responsiveness across the entire production lifecycle. Real-time data from sensors, machines, and control systems feed into the digital twin, which in turn enables simulations, scenario planning, and automated decision-making. This evolution is particularly significant in complex industrial environments where operational continuity, risk mitigation, and sustainability are top priorities. Despite the substantial benefits, practical implementation faces several challenges, including data interoperability across diverse platforms, cybersecurity concerns, and the need for a digitally skilled workforce. However, the growing adoption of open standards, AI-driven analytics, and secure cloud infrastructures is gradually addressing these barriers. As industries increasingly seek resilient and adaptive solutions, the synergy between digital twin technology and automation is emerging as a cornerstone of smart, data-centric manufacturing strategies. This shift signals not just a technological upgrade, but a fundamental transformation in how industrial intelligence is designed and applied.

Keywords: Digital twin, automation, smart manufacturing, technological map, Industry 4.0, virtual commissioning, process optimization, intelligent control, industrial intelligence, system integration.

Introduction. In the contemporary era of Industry 4.0, the integration of advanced digital technologies into industrial systems is radically transforming the way manufacturing and processing plants operate. Among these technologies, the concept of the digital twin has emerged as a critical innovation that bridges the gap between physical systems and their virtual representations. The digital twin refers to a dynamic digital replica of a physical entity, system, or process, which is continuously updated with real-time data, allowing for monitoring, simulation, optimization, and predictive maintenance. This paradigm shift is particularly significant when applied to the digitalization of a plant's technological map—a comprehensive schematic that encompasses the layout, processes, equipment, and interconnections within an

industrial facility. Traditionally, such maps were static and manually updated, limiting their utility in the face of real-time operational challenges. However, with the advent of digital twins, these maps can now be transformed into living models that mirror the actual state of the plant, enabling enhanced visibility, adaptability, and decision-making.

The synergy between digital twins and automation further amplifies the efficiency and intelligence of industrial systems. Automation, in this context, refers to the deployment of control systems, such as SCADA (Supervisory Control and Data Acquisition), PLCs (Programmable Logic Controllers), DCS (Distributed Control Systems), and IoT-enabled devices, to operate machinery and processes with minimal human intervention. When integrated with digital twins, automated systems can leverage real-time data to dynamically adjust parameters, detect anomalies, predict failures, and implement corrective actions in a closed-loop manner, thereby fostering a self-regulating and intelligent manufacturing environment. This not only reduces downtime and operational costs but also enhances flexibility and responsiveness to changing market demands. Moreover, the implementation of digital twins in industrial automation facilitates the creation of a cyber-physical production system, in which physical processes are deeply interconnected with digital models and intelligent analytics. The digital twin serves as a centralized data hub, enabling interoperability between various subsystems, improving cross-departmental communication, and supporting data-driven decision-making at all levels—from control room operators to strategic planners. By enabling simulations before physical execution, digital twins also support virtual commissioning, stress testing of process modifications, and scenario analysis for risk assessment and sustainability planning.

The digitalization of the plant's technological infrastructure, therefore, is not merely a technological upgrade but a strategic rethinking of how information is harnessed, visualized, and utilized throughout the plant lifecycle. This transformation aligns with the broader objectives of smart manufacturing and sustainable development by promoting resource efficiency, environmental monitoring, and energy optimization. As global industries increasingly prioritize agility, resilience, and sustainability, the integration of digital twin technology with automated control systems emerges as a cornerstone of future-ready industrial operations. This paper aims to explore the theoretical foundations, practical implementation strategies, and long-term implications of this integration, while also addressing the challenges related to cybersecurity, data interoperability, workforce adaptation, and investment cost. Through a comprehensive analysis, it seeks to demonstrate how the interaction between digital twins and automation redefines the boundaries of industrial intelligence and operational excellence.

Literature Review. The convergence of digital twin technology and automation in industrial systems has garnered significant scholarly attention over the past decade, particularly within the broader context of Industry 4.0 and smart manufacturing paradigms. Numerous studies have sought to define the foundational principles of digital twins, investigate their technical architectures, and evaluate their operational impacts in various industrial sectors. According to Grieves and Vickers (2017), who are often credited with formalizing the modern conceptualization of the digital twin, this technology is more than a mere digital model—it embodies a continuous, bidirectional flow of data between the physical and digital realms, thus

enabling real-time synchronization, predictive diagnostics, and performance optimization. Their work laid the groundwork for subsequent research that has explored the applicability of digital twins across domains such as aerospace, automotive, energy systems, and, more recently, process industries.

In the context of process plant operations, several researchers have emphasized the transformative potential of integrating digital twins with real-time automation systems. Kritzinger et al. (2018) distinguish between various levels of digital representation, ranging from static digital models to dynamic digital twins that are fully integrated into operational workflows. Their classification underscores the necessity of not only developing accurate digital models but also embedding these within intelligent feedback loops enabled by automation technologies such as SCADA, PLCs, and Industrial Internet of Things (IIoT) platforms. This integration is echoed in the works of Qi and Tao (2019), who argue that the value of digital twins is maximized when they are combined with closed-loop automation systems capable of self-adjusting based on real-time insights. They propose a layered digital twin architecture consisting of data, model, and service layers, which collaboratively support adaptive control and decision-making processes in complex manufacturing environments.

Further literature highlights the use of digital twins in enhancing plant technological mapping, which involves not only the visualization of physical layouts and process flows but also the simulation and validation of operational scenarios. Biesinger et al. (2020) explore how digital twins can augment traditional P&ID (Piping and Instrumentation Diagram) systems by embedding operational intelligence and historical data within the schematic. This evolution allows for more robust design, planning, and fault diagnosis capabilities. Similarly, Boschert and Rosen (2016) emphasize the use of digital twins for lifecycle management, noting that continuous updates from sensors and actuators make it possible to monitor asset degradation, assess operational efficiency, and extend equipment lifespan.

A substantial body of literature also investigates the practical implementation challenges associated with digital twin deployment in automated industrial environments. Challenges such as data interoperability, model accuracy, cybersecurity risks, and high implementation costs are recurring themes. Research by Negri et al. (2017) outlines a framework for developing digital twins in manufacturing systems and stresses the importance of standardized communication protocols and middleware to ensure seamless data exchange between components. Moreover, Colombo et al. (2019) discuss the necessity of robust cybersecurity frameworks, as the growing connectivity between physical assets and digital infrastructures increases the system's vulnerability to cyber threats. They suggest that the integration of digital twins must be accompanied by multilayered security strategies, including real-time intrusion detection, secure data transmission, and access control.

In parallel, there is a growing discourse around the role of digital twins in enabling sustainable and energy-efficient manufacturing. Research by Tao et al. (2020) illustrates how digital twins can support environmental monitoring and emission control through the real-time tracking of resource consumption and waste generation. By simulating different operational strategies,

digital twins can identify optimal pathways that minimize environmental impact while maintaining production efficiency.

Overall, the literature underscores the multifaceted benefits of integrating digital twins with automation—from operational excellence and predictive maintenance to sustainability and agile production. However, it also emphasizes the need for continued research into interdisciplinary challenges, including system integration, human–machine interaction, workforce training, and economic feasibility. This review of the current state of knowledge serves as a critical foundation for analyzing the real-world application of these technologies in plant-level technological mapping and automation processes, guiding both theoretical exploration and practical implementation in future industrial settings.

Discussion. The integration of digital twin technology with plant automation represents a fundamental shift in how industrial facilities are designed, managed, and optimized. The discussion surrounding this integration reveals both immense potential and significant complexity. One of the most striking aspects is the digital twin’s capacity to act as a central intelligence hub, where vast streams of data from sensors, actuators, and control systems are collected, contextualized, and transformed into actionable insights. In traditional industrial setups, the technological map served primarily as a static representation of pipelines, equipment, and process flow diagrams. However, in a digitized environment, this map becomes a dynamic, evolving entity capable of reflecting real-time changes, predicting anomalies, and supporting rapid decision-making. The real value of a digital twin becomes evident when it is tightly coupled with automated control systems. This coupling enables what can be referred to as a cyber-physical feedback loop, wherein real-time data from the physical plant informs the digital model, which in turn drives automated decisions that adjust the physical system. For example, if a critical parameter such as pressure or temperature deviates from the optimal range, the digital twin—supported by historical data and machine learning algorithms—can predict the potential consequences and instruct the automated system (e.g., via SCADA or PLC) to initiate corrective action before the deviation causes system-wide disruptions. This level of intelligence and responsiveness marks a departure from the reactive strategies of the past and moves the industry closer to predictive, even prescriptive, operational paradigms.

Another point of discussion lies in the transformative effect of this interaction on operational transparency and decision support. Plant operators and engineers gain enhanced situational awareness through immersive digital interfaces that allow them to monitor not just where equipment is located, but how it is performing in real time, why certain changes are occurring, and what potential risks lie ahead. This visibility is particularly valuable in complex or hazardous process industries, such as chemical, petrochemical, or energy production, where small disturbances can escalate into major incidents. By simulating various "what-if" scenarios through the digital twin, operators can better anticipate failures, schedule maintenance proactively, and avoid unplanned shutdowns—all of which contribute to improved plant availability and cost savings.

From a design and commissioning perspective, digital twins also offer unprecedented advantages. During the planning phase of a plant or a new process line, digital twins can be used to simulate

the entire lifecycle—from initial process flows to installation logistics to operational behaviors—allowing engineers to identify and rectify design flaws long before physical implementation begins. This is particularly relevant in the context of virtual commissioning, where control strategies are tested and optimized within the digital environment, reducing the risk of costly changes during real-world commissioning. Additionally, the digital twin can continue to serve as a digital record throughout the plant's life, supporting future upgrades and retrofits without the need for time-consuming manual documentation. However, the discussion would be incomplete without acknowledging the existing barriers to widespread implementation. One of the primary challenges is ensuring interoperability between the diverse systems and platforms involved. Industrial environments typically feature a heterogeneous mix of legacy equipment, proprietary protocols, and fragmented IT infrastructures, which complicate seamless integration. Furthermore, the development and maintenance of accurate and high-fidelity digital models require not only significant investment in data infrastructure and modeling tools but also skilled personnel capable of interpreting and managing these systems. This raises the issue of workforce readiness and the necessity for targeted training programs to bridge the knowledge gap between traditional engineering disciplines and modern digital technologies.

Cybersecurity also remains a major concern, as the increased connectivity inherent in digital twin systems creates new attack surfaces. Ensuring the confidentiality, integrity, and availability of real-time industrial data is essential for maintaining operational reliability and protecting sensitive information. Robust cybersecurity frameworks must be developed in parallel with digital twin initiatives to address these risks proactively. While the digitalization of a plant's technological map through the integration of digital twins and automation introduces technical, organizational, and cultural challenges, the potential benefits far outweigh the obstacles. From enabling data-driven optimization and predictive maintenance to enhancing safety and environmental compliance, this convergence is poised to redefine industrial excellence in the digital age. The future of smart manufacturing depends heavily on our ability to scale, secure, and sustain these technologies within the ever-evolving industrial ecosystem.

Conclusion. The integration of digital twin technology with automated systems represents a transformative step in the evolution of modern industrial operations. This research has highlighted how digitalizing a plant's technological map enables a shift from static process documentation to dynamic, real-time environments that support intelligent decision-making, operational efficiency, and predictive control. Through the coupling of virtual models with physical systems, industries are now better equipped to respond to variability, identify inefficiencies, and reduce downtime through data-driven insights and continuous optimization.

Digital twins, as interactive and continuously updated digital representations of physical processes, offer more than just visualization—they enable simulation, analysis, and automation in ways that traditional methods cannot. When combined with advanced control systems, they serve as the core of cyber-physical environments, facilitating proactive interventions and seamless plant management. This synergy allows for the anticipation of failures, more efficient maintenance planning, improved safety, and enhanced system resilience. Despite the clear advantages, practical implementation still faces challenges such as technological complexity,

data integration barriers, cybersecurity threats, and the need for skilled human capital. Addressing these issues requires interdisciplinary collaboration, robust digital infrastructure, and a long-term commitment to workforce development. Nevertheless, the direction is clear: as digital twin and automation technologies continue to mature and integrate, they will become indispensable tools for the future of intelligent, adaptive, and sustainable manufacturing systems. The digitalization of the plant's technological map is not merely a technological innovation but a strategic enabler of industrial transformation. Its successful deployment will redefine how we perceive, operate, and evolve industrial systems in the era of Industry 4.0 and beyond.

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