# Leveraging Digital Twins for Enhanced PLC Performance and Maintenance in Industrial Automation

KLAOUNTIO MITA, IOANNIS GIACHOS*, EVANGELOS C. PAPAKITSOS, MICHAIL PAPOUTSIDAKIS, NIKOLAOS LASKARIS, CHRISTOS DROSOS
Department of Industrial Design & Production Engineering
University of West Attica
Olive Grove Campus, 12241 Egaleo
GREECE

*Abstract:* - This study analyzes the new use of digital twins technology in programmable logic controllers (PLC) within the scope of industrial automation. The goal of this work is to show the possibilities of applying digital twins in conjunction with PLCs for industrial purposes. The integration of digital twins with PLCs may provide substantial benefits in operational efficiency, predictive maintenance, process optimization, and innovation across various sectors. Following the methodology of bibliographic survey, which is rather limited due to the novelty of the topic, several examples have been spotted. Through these examples, the impact of digital twins on production optimization, maintenance, monitoring, remote operation, and virtual commissioning are examined. The case examples also address challenges related to guaranteeing the quality of data constraining scalability, and issues of security in the implementation of digital twins and PLCs. The paper explores future directions, such as advanced analytics, IoT applications, virtual reality, and standardized interface metrology. The development of digital twins in regards to PLCs has enormous potential and can help organizations to become more efficient, optimized, and competitive in industrial automation. Embracing this technology provides new opportunities for organizational operations and drives improvement on a continuous basis.

*Key-Words:* - PLC, PLC performance, PLC maintenance, digital twins technology, industrial automation, process optimization, HRI

Received: March 3, 2025. Revised: July 5, 2025. Accepted: August 7, 2025. Published: September 9, 2025.

## 1 Introduction

The field of industrial automation has undergone significant advancements, revolutionizing manufacturing processes and boosting productivity. Programmable Logic Controllers (PLCs) have played a crucial role in automating and controlling various industrial operations. However, as technology continues to evolve, new opportunities arise to further enhance PLC performance and maintenance capabilities. One such opportunity lies in the integration of digital twin technology, which creates virtual replicas of physical assets and enables real time monitoring, analysis, and optimization. The automation of industrial processes is an ever-evolving domain which has automated manufacturing processes and increased productivity. Automation and control of industrial processes are performed with the aid of computers, which is done with the help of Programmable Logic Controllers (PLCs). With the passage of time, technology evolves, and so do the possibilities of improvement of PLCs regarding performance, maintenance, and operation. One of the possibilities for further enhancement of programmable logic controllers is their digitization along with their digital twin technology that helps in creating virtual simulacra and facilitates real time supervision, analysis, and optimization.

Creation of representatives from physical assets has helped machines or production lines to be automatically controlled and have helped in real time data calc gain and valuable insights to improve processes. Integrating digital twins into PLCs can allow for the unlocking of previously impossible levels of operational efficiency, predictive maintenance, and process optimization, improving overall productivity. Integration of digital twin technology into current systems has opened new frontiers for all industries.

This paper intends to analyze the integration of digital twins and PLCs in the industrial automation systems industry. Enhancing PLCs with digital twins as performance monitoring systems enables manufacturers to optimize maintenance tasks, and productivity. The paper will discuss the applications of digital twins in PLCs, therefore analyzing the integration of these technologies with respect to benefits, challenges, and advancements. The authors in [1] made a first attempt to approach the usage of digital twins' technology in PLCs for production logistics, but in general this field lacks extensive exploration.

The following sections focus on the importance of digital twin technology with respect to industrial automation, aiming to provide explanations throughout. This discussion will focus on the basic elements of digital twins and their advantages, and the implementation challenges. Furthermore, the discussion will cover the role of PLCs in industrial automation systems, including their shortcomings, and inadequacies. In that respect, the integration of digital twins with PLCs will be discussed regarding architecture, design considerations, and results in real time monitoring and control.

This paper will look into the possibilities of how the integration of digital twins can enable early fault detection and predictive maintenance to boost system reliability and reduce downtime. In addition, the potential for operational efficiency and process optimization will be examined through data-driven decision-making, real-time process optimization, and advances in energy and resource efficiency. Throughout this paper, the concerns dealing with the integration of digital twins with PLCs, like issues of data security and privacy, integration difficulties, and interoperability, will also be discussed. Furthermore, it will focus on the identifying the emerging issues and potential future directions of development within this rapidly evolving area. The above will be explained using multiple case studies from various production sectors.

The purpose of this paper is to explore the novel uses of digital twin technology, with an emphasis on PLCs, to help expand the available literature, stimulate new ideas, and highlight the possible impacts for the industry. With this approach, it is easy to imagine a future where integrating digital twins with PLCs transforms industrial automation to allow manufacturers to optimize processes, reduce outages, and increase productivity and efficiency.

# 2 Digital Twins Technology

Digital twins can be defined as being the virtual duplicates of real assets, systems, or processes. They capture both physical and digital dimensions, providing a real time interface and integration of the object with its digital counterpart [2]. A digital twin comprises three essential components:

a) Physical Object: This part represents either a machine, production as applied to systems, building or an entire manufacturing plant, all of which have a corresponding asset or system that is being replicated. The object has operational characteristics, behaviors and other relevant data associated with it as the entity in real life.

b) Virtual model: The virtual twin is the model of the physical counterpart. It contains all relevant information with respect to geometry, structure, properties, and behavior of the asset during its displacement. The virtual model constantly reflects the real-time status changes of the asset which are also changes physical models.

c) Data integration and analytics: Integration of data sources is critical in twin technology. Gathering and integration of real time data collected from many sources of IoT devices and sensors are done to the model. This is further analyzed by using advance analytic techniques like ML and AI to extract the best meaningful output to be aid decision making processes.

Consequently, a digital twin is a physical system's digital replica that simulates its behavior within a virtual environment. The digital twin, in imitating the physical system, is capable of: providing guidance towards appropriate actions in real time, alleviating unsolicited occurrence of events, optimizing processes, monitoring and assessing the operating profile, forecasting failures, and uncovering opportunities for improvement with respect to operations.

## 2.1 Importance of Digital Twins in Industrial Automation

The digital twins' technology can be of great use to industries by offering a virtual representation of their assets on the production floor, as well as providing real time results of the ongoing processes. In addition, it allows predictive maintenance, facilitates better decision making, and improves operational efficiency [3]. With the assistance of data analytics, industries are able to elevate their productivity, effectively allocate resources, minimize equipment downtime, and encourage continuous improvements with the help of digital twins [4]. This technology provides important benefits in the scope of industrial automation including:

a) Real Time Monitoring and Analysis: The integration of sensors as well as IoT devices with digital twins makes it possible for the manufacturers to monitor and analyze the performance, behavior, and condition of their physical assets in real time, which is very useful. This allows for proactive monitoring, early fault detection, deviation response, and anomaly mitigation.

b) Simulation and Optimization: Digital twins allow for the simulation of various hypotheses without any impact to the physical system. This way, different scenarios can be tested which aids in the optimization of various processes and also helps predict and analyze the impact of different factors. Critical bottlenecks can be identified, inefficiencies optimized, and operational parameters enhanced to improve overall efficiency.

c) Predictive Maintenance: With the availability of real-time data from digital twins, manufacturers can adopt predictive maintenance methodologies. The implementation of algorithms in machine learning enables the identification of trends or precursors indicative of issues, thus facilitating proactive maintenance actions. Operational interruptions during maintenance are minimized whilst the life expectancy of the equipment is maximized and the dependability improves.

d) Performance Optimization: Continuous performance optimization is achieved through digital twins. By monitoring and analyzing the data obtained from the physical technological system, manufacturers can actively identify technological advances pertaining to changes in energy use, waste reduction, productivity improvement, and general optimization of the system.

e) Remote Monitoring and Control: Remote monitoring and control features are made possible by the digital twin technology, which is very important in situations when access to a particular system is difficult. The operator can work with the digital twin for monitoring and control purposes and make real-time decisions guided by data supplied from the physical system.

### 2.2 Implementing Digital Twins

The application of digital twins in industrial automation comes with assistive benefits such as:

a) *Benefits:*

- Real-time tracking of asset performance coupled with visibility of operational processes.
- Enhanced accuracy and up-to-date relevancy in decision making.
- Reduced and optimized downtime due to improved maintenance strategies.
- An increase in the life-span of the asset.
- Maintained and uninterrupted operational efficiency alongside productivity.
- Predictive capabilities for preemptive fault detection and maintenance.

b) *Challenges:*

- Interoperability and data integration: The merging of data from different systems and sources can be complicated as it requires integration and unobstructed data flow between different systems.
- Data management and computational intensive resources: Utilizing digital twins in extensive industrial systems may present challenges in data handling, resource allocation, and computational power.
- Data protection and sensitive information: Protecting important information and sensitive data on intellectual property and customers is one of the primary challenges.
- Specialized training: The creation and maintenance of digital twins requires unique knowledge in their corresponding fields, such as modelling, which other areas may not have.

## 3 PLC and Industrial Automation

In controlling PLCs for a specific technology context, concepts derived from computer-based control systems are applied. To manage PLCs, microprocessors are employed allowing the use of digital computers to control machinery and manage processes. Under harsh industrial settings, real time controls is possible [5].

In PLCs, logic sensors and other units form a contact and provide input signals, while relays provide equipment control signals. With PLCs, output signals are created to control other devices. In the case of PLCs, programming is so done in ladder logic was implemented as it simplify logical or sequential operations representation [5]. Since every industry has varied tasks and specific needs that require automation, PLCs aid in creating tailored frameworks, monitoring systems, and automating machinery, which is further enhanced due to their flexibility and reliability. Automated machinery, control systems, and manufacturing process monitoring stems from the high agility, speed, and broad system or device compatibility provided by PLCs alongside deterministic control [5].

To meet designated requirements such as altering the functionality of a PLC, accessories, and modules such communication, function, and input/output (I/O) modules can be added. Communication with other devices and systems is enhanced with the support of other protocols and allows for remote access. Under industrial automatization systems such connectivity, data exchange, and system integration can be achieved.

### 3.1 PLCs in Industrial Automation Systems

PLCs are essential components of industrial automation as they provide accurate and flexible control solutions. Their primary functions and advantages include:

a) Endurance and Trustworthiness: PLCs function in extreme industrial conditions, including harsh temperatures, vibrations, and electromagnetic interference. They are trusted to operate in difficult situations without fail, to deliver high performance.

b) Programmability and Flexibility: PLCs support different programming styles which enables sophisticated strategies of implementing control logic. They may be programmed in different ways, allowing engineers and technicians with different specializations the opportunity to work with them.

c) Real Time Control: Real time control is a characteristic feature of PLCs. An ascribed monitoring and reaction system enables the precise observation and response to input signals. As a result, important decisions and swift actions to control, carry out, and manage processes are done better, thus improving industrial process efficiency and safety.

d) Options of connection and Sharing: PLCs enable interaction with other devices and systems like sensors, actuators, HMIs, and SCADA systems. Communication is done through various protocols which simplifies data exchange and sharing within industrial automation systems.

e) Safety Features: PLCs provide safety functions and protocols for protecting operators, machines, and even the environment. Depending on the industry type, they manage safety rated inputs and outputs, emergency stop operations, and compliance with safety regulations.

### 3.2 Limitations and Areas for Improvement

During the automation revolution, the Programmable Logic Controller (PLC) has remained a crucial device within industrial control systems that has provided commanding functions for feedback control loops at a lower level. Yet, even with the evolution of automation technologies driven by the Industry 4.0 paradigm and its ecosphere of interconnection, there has not been a modernization PLC to cater for the specific functionalities required by an Industry 4.0 control system [6]. PLCs have certainly brought value to the automation of industries, but there remain gaps in improvement, including:

a) Scalability: There is a demand for more PLC solutions that can efficiently manage process--and system--integration at a higher level of complexity. To support growing demands in higher I/O counts, processing requirements, networking, and general computing automation, systems need to be more complex in modularity and automation.

b) Integration with Advanced Technologies: Cloud and edge computing, as well as data analytics, should all be PLC compatible for maximum use. Such technologies enable more efficient and accurate real-time decision-making, predictive maintenance, and process optimization.

c) User Friendliness: Expanding the user base of a PLC can be done by making the programming and configuration processes simpler. More such users can be empowered and educated through easing-of IDEs, lowering the learning curve, which enhances usability.

d) Cybersecurity: Contingent on the level of connectivity of a PLC is the extent of cybersecurity measures required. The automation systems are wealth protected from numerous threats that compromise trusted cyber-physical vulnerabilities and unauthorized access.

## 4 Digital Twins with PLCs

Overcoming these shortcomings and seeking improvement opportunities could improve the performance of PLCs and their impact on the evolution of industrial automation. This advancement enhances system efficiency, security, and interconnectivity. In the next part of this paper, we will describe the development of digital twins and their integration with PLCs, where both technologies are synergistically combined to transform performance, maintenance, and optimization in automation systems.

The union of digital twins and programmable logic controllers (PLCs) is one of the major focuses of industrial automation. It requires careful attention to the integration’s architecture and systems design to maximize efficiency. Several challenges are bound to arise with the automation integration. One of the most vital challenges is the construction of an adequate data dissemination and data synchronization process with the digital twine over the PLC. This encompasses establishing rules, data standards, and communication methods necessary for real time data updating.

The integration must allow monitoring in real time as physical systems, containing the data through the twin, are scanned. Furthermore, it must allow controlling the system from the virtual model insights. Lastly, performance and scalability still matter. Exponential growth in the level of data and system complexity require systems to be built in, even in the middle of the process. Therefore, scalability and computational power together with network capabilities should be handled during the overall design to ensure reasonable performance and optimal results as well.

The combination of PLCs and digital twins allows industrial automation systems to use advanced monitoring and control tools. The digital twin can retrieve data in real time from the physical system through sensors and PLCs. This data is sent to the virtual model to be analyzed, visualized, and decisions made. Through the digital twin, the system can monitor the state of the system in real time. As such, any deviation from the operating conditions can be captured. Alarms conditions and thresholds could be created which allow the system to perform some actions in case of specific alert signaled.

Additionally, the integration allows for remote supervision and control of the actual system. The combination of digital twins and PLCs also makes it possible to optimize performance through simulations. The virtual model is capable of simulating diverse situations, testing theories, and fine-tuning process parameters. This assists in detecting obstacles, controlling processes, and enhancing efficiency without affecting the physical system.

In addition, the digital twin technology can be used to leverage both historical and real time data for predictive analytics. This enables the foreseeing of system behavior, recognizing patterns, and optimizing processes to achieve peak performance. In addition, the digital twin provides valuable information regarding energy consumption, and other auxiliary resources. Accordingly, the opportunity for energy saving, cost reduction, and other sustainability measures can be identified. All in all, the implementation of digital twins with PLCs enhances performance, supports predictive maintenance, and optimizes industrial automation processes. Manufacturers gain the capability of achieving higher efficiency levels while reducing downtime and making data driven decisions for continuous improvement.

# 5 Prediction and Detection

## 5.1 Introduction to Predictive Maintenance

The modern strategy of predictive maintenance employs sophisticated analytics and machine learning algorithms to detect the likelihood of impending equipment failures. Predictive maintenance strives to optimize equipment maintenance by minimizing downtime and costs, streamlining maintenance schedules, and reducing service interruptions through data from sensors, maintenance logs, and the digital twin model.

## 5.2 Integration of Digital Twins and PLCs

Utilizing both digital twins and PLCs in conjunction strengthens the benefits predictive maintenance offers:

a) Data Fusion and Analysis: The digital twin comprises an aggregate up-to-date collection, along with historical data that features system parameters, maintenance history, and sensor readings. Together with PLC data, increased computing power can apply advanced algorithms to perform in-depth analysis, find patterns, anomalies, and foresee failures more accurately than previously possible.

b) Continuous Condition Monitoring and Prognostics: A digital twin is tasked with capturing the performance of a physically observable system and its deviations in real time. Digital twins can compare real-time data to established baselines and performance models to discern observable indications of faults. This allows planning turnaround maintenance activities ahead of time.

c) Maintenance Planning and Alert Creation: In the event of an anomaly or potential fault detection, the digital twin notifies or alerts maintenance personnel. These maintenance alerts are critical for informing teams about issues that have been detected, therefore enabling maintenance to prioritize and schedule activities according to the criticality of the faults, as well as the resources that are available. This level of foresight aids in mitigating the risk of unplanned downtime while also optimizing maintenance resources.

## 5.3 Fault Detection and Diagnostics

The incorporation of PLCs and digital twins technologies will enhance fault detection and diagnostics by employing:

a) Continuous System Behavior Tracking: The disabled twin exploits the system's PLC to receive real-time data. This data enables the digital twin to monitor system behavior synchronously. With the aid of sophisticated analytical methods, the digital twin could diagnose any anomalies, breakdowns, and deviations from the set standards. Faults should be detected as soon as possible, which should enable timely corrective actions to be taken.
b) Faulty Events Systems: The digital twin aids in root cause analysis when a fault or deviation occurs. The digital twin assists in identifying the causes of the fault by simulating the system's behavior and comparing it with provided data, examining multiple scenarios. Understanding the root causes greatly enhances the ability to troubleshoot by implementing specific corrective efforts, minimalizing the time and effort needed.
c) Reporting and Data Visualization: The digital twin has the models state which is represent visually and includes both historical and real time data. This visualization helps in diagnostic faults and enables maintenance teams to comprehend the nature of faults seamlessly. The comprehensive reports produced by the digital twin depict insightful analysis of fault reports. Such analysis enhances decision making and facilitates long-term system enhancement through automated monitoring and controlling.

# 6 Efficiency and Optimization

## 6.1 Enhancing Operational Efficiency

Combining PLCs with digital twins creates new prospects for improving operational efficiency in industrial automation systems. This integration makes possible several changes aimed at boosting productivity:
a) Data Collection: The digital twin is able to monitor the system's performance using sensors and PLCs. Providing operators with an up-to-date view of the system performance allows him/her to make real-time adjustments, identify bottlenecks, detect inefficiencies and overall improve productivity through the adjustments.
b) Equipment Maintenance: Equipment failures can be avoided by planning maintenance during optimal production windows and scheduling maintenance proactively using predictive analytics.
c) Intelligent Resource Allocation: Advanced resource allocation and utilization create opportunities to optimize the use of labor, energy, raw materials, and resources which leads to improved productivity and reduction in costs and wastage.

## 6.2 Process Optimization through Digital Twin Simulations

Operators gain incredible value from decision support when using a digital twin in conjunction with a PLC. One promising benefit of this integration is the application of machine learning and artificial intelligence within the twin, otherwise referred to as a digital twin. With the digital twin having the ability to process real-time data, actionable insights can be provided. In turn, operators are able to make data driven decisions in real-time which improves efficiency by enabling optimization alongside improved operational flow.
Moreover, the digital twin can act as a constant and vigilant monitoring mechanism of the associated systems. It continuously analyzes performance metrics with the aim of recognition and deviation notification toward set norms. This type of prompt alert generation, and more, enables operators to react and act proactively which saves them from potentially more severe problems which can arise as an issue escalates. With quick response action, operators is able to retain system reliability while minimizing downtime as well.

Now, digital twin has the potential in assisting participants with ad hoc simulations which serves as a further aid in decision making. These include scenario planning exercises, planning in terms of different operational strategies, and trying simulations concerning aforementioned processes such as resource allocation, changes to optimized planning in terms of capacity, and more. The integration of scenarios, variables, and parameters in the process enable enhanced informed decision making to smooth execution and maximal operational efficiency.

To conclude, with the digital twins integrated with PLCs, real-time decision support is enabled. By utilizing advanced analytics, alert generation, and scenario planning, data-driven decisions can be aided, counters anomalies, and operations can be optimized for greater efficiency and agility.

## 6.3 Integration with Business Systems

The automation level of the digital twins with PLCs is more than just an addition, as it allows greater integration with other business systems for holistic optimization. For starters, connecting the digital twin with the supply chain management systems provides a complete overview of the entire value chain. This includes monitoring demand signals, demand forecasts, inventory levels, and production planning. Such integration fosters better coordination, synchronization, and resource optimization along the entire supply chain. In this manner, lead times, customer satisfaction, and resource utilization are improved.

Also, the addition of the digital twin to enterprise resource planning (ERP) systems improves the coordination of working as it facilitates data transfer in real-time. Stakeholders receive up-to-the-minute data about the status of production, inventory, and available resources. Cooperation helps in making decisions and increases the coordination of different units thereby improving operational performance.

Furthermore, the digital twins association with business systems enables stakeholders to all levels of the organization to take actions based on reliable data. With the assistance of the digital twin and its real time data and analytics, executives, managers, and operators make informed decision to improve operational efficiency, optimize processes, and accomplish strategic business goals [7].

With the expansion of the digital twins connections from PLCs to other business systems, industrial automation systems achieve superior levels of operational efficiency, productivity, and process automation. This architecture supports performance monitoring and simulation, process optimization, and interaction with business systems in real time. This, in turn, fosters improvement and enhances competition in the ever-changing industrial environment.

## 6.4 Performance Analytics and KPI Tracking

The enhancement of digital twins with programmable logic controllers (PLCs) sister controllers provides industrial automation with a new asset: complete performance analytics and Key Performance Indicator (KPI) monitoring, so far mentioned in no other citation. These attributes are paramount for optimizing processes [8].

Incorporating the Digital Twin Technology (DTT) with the Programmable Logic Controller (PLC) allows manufacturers to evaluate performance from various comprehensive perspectives. The Digital Twin captures data in real-time, thus reflecting the system virtually with a physical model and providing an insight of productivity in relation to defined indicators. Such indicators of performance encompass efficiency, productivity, and quality, among others.

Moreover, such integration allows for the monitoring of Performance Metrics, or Key Performance Indicators (KPIs), which are important for measuring a given success level of processes. KPIs create a measurable yardstick of value against previously defined goals and benchmarks. With Digital Twins connected with PLCs, the possibility of real-time data collection and analysis for KPI monitoring becomes continuous.

The combination of digital twin technology and PLCs enable accuracy with performance optimization which becomes more predictive and calculative. Through the analyzed data by the digital twins, it becomes effortless to identify the scopes of improvement, spot the inefficiencies, and apply optimizations accordingly. This will enhance reasonable and well-informed decisions meant for process refinement.

Ultimately, integrating digital twins with PLCs helps manufacturers achieve comprehensive mastery over their industrial processes. By monitoring the performance analytics and KPIs, the data helps in realizing process refinement, efficiency improvement, and achievement of operational goals.

## 6.5 Real Time Decision Support

Operators gain greater efficiency and flexibility in their roles through enhanced real time decision support made possible with digital twins in conjunction with PLCs.

Supporting digital twins is advanced analytics features. Techniques such as machine learning and Artificial Intelligence allow a digital twin to analyze data streams in real time. Data analysis at this scale enables operators to enhance agility and take informed decisions on the remits, thereby improving operational effectiveness.

Moreover, the digital twin analyzes the system's performance and automatically tracks the metrics of relevance such as system identifier under monitoring set and draws up a baseline from which intelligent alerts are generated. When critical or abnormal operations parameters are reached, intelligent alerting with adequate notification will be executed. Through such notifications, timely measures can be put in place to avoid potential escalation of problems therefore ensuring smooth operation.

The digital twin's simulation features enhances its functionality for decision support. This allows operators to conduct scenario planning by examining the consequences of various strategies on operations. This includes evaluating the division of resources, changes in processes, as well as planning for total capacity. Considering these scenarios enables operators to make strategic decisions that optimize all workflow processes and guarantee precision operation.

# 7 Examples

In this part, we triad hypothetical examples of possible applications of digital twins technology within programmable logic controllers (PLCs) in subsections 7.1-7.4.

Initial attempts have already been made, as for example in [10], where they developed a digital twin for the production line using TIA PORTAL [9]. The intention of these examples is to demonstrate some of the numerous possibilities and advantages that can be achieved by incorporating digital twins into PLCs across different sectors. For all the examples described below, the integration of a digital twin into a system to optimize production processes is made possible primarily through the controlling devices known as programmable logic controllers (PLCs). As described in Chapter _ on Digital Twin, PLCs connect the physical system to the digital twin and provide real-time data streams from sensors located on the equipment in the plant.

These may not be literal, but they do depict the possibilities of what organizations may achieve with the use of digital twins regarding operational efficiency, predictive maintenance, remote monitoring, virtual commissioning, and many more. The examples illustrate how organizations could adopt various strategies utilizing digital twins to enhance process optimization, asset performance, decision intelligence, and innovation within their industries.

## 7.1 Predictive Maintenance

A manufacturing facility can blend PLCs with digital twins to enable predictive maintenance strategies. These digital twins not only create an image of the machine, but they also analyze sensor data, maintenance history, and the surrounding environment in real time to monitor machine performance. By applying machine learning techniques, the digital twins can uncover patterns and detect signs of equipment deterioration or imminent failures. This data can help the facility manage maintenance service, inventory necessary parts, and adjust resource allocation in a timely manner. Such approach helps to mitigate equipment idling, lower maintenance expenses, and enhance production efficiency.

## 7.2 Remote Monitoring and Control

To facilitate remote monitoring and control of the system infrastructure, an energy distribution company employs digital twins interfaced with PLCs into their operations. Digital twins gather, within real-time, information from PLCs located at substations and interfacing portions in transmission lines, including the voltage level, power flow, and current status of the equipment. Through the digital twin interface, system operators can access and visualize, at great detail, the performance of the entire system remotely. This insight allows them to make decisions that improve power distribution, troubleshoot issues, and prevent possible interruptions. In turn, this type of settlement leads to improved operational efficiency, minimized outage duration, and enhanced reliability of the energy distribution network for the energy distribution company.

## 7.3 Asset Performance Management

An oil and gas company seeking asset performance management improvement may use digital twins together with PLCs. At this instance, digital twins can monitor major apparatus under field supervision such as pumps, compressors and valves. The digital twins can now monitor operating conditions and record vibration levels and maintenance for each piece of equipment. Using contemporary technology, performing analytics predictive enable but also recommend mechanics to address the real issues detected. Consequently, this leads to greater equipment uptime, lower maintenance expenditures, and increased operational safety in oil and gas operations [10].

## 7.4 Smart Grid Optimization

A utility company can optimize the operation of their smart grid by incorporating digital twins with PLCs. These digital twins integrate with smart meters, substations, and other renewable energy resources to provide real time data insights, enabling operators to monitor grid performance, optimize power distribution, and identify anomalies. The information provided by these digital twins through data analysis is beneficial for load balancing, demand forecasting, and the integration of renewables. With such an integration, the utility company improves grid reliability, energy efficiency, and meets their sustainability goals.

# 8 Challenges and Future Directions

The benefits an organization could reap from implementing digital twins with PLCs can be significant. However, it does come with its own challenges.

Overcoming data quality and integration issues can be quite challenging. To create effective digital twins, data from PLCs and other sources needs to be accurate, reliable, and consistent. Integrating data from different systems requires data governance frameworks that are capable of accommodating disparate systems, synchronizing data, and validating a given set of data's quality.

The next major hurdle to consider is scalability and complexity. Synchronization, while maintaining real time performance, between the physical system and digital twin is already a monumental challenge in itself, but becomes increasingly complex for large scale industrial systems. It's crucial that an architecture is designed for optimized performance that can manage large volumes of data without compromising on speed.

Aside from the previously mentioned challenges, advanced security is critical as well. When merging a digital twin with a PLC, tremendous emphasis on the protection of sensitive data is required. The digital twin and PLCs need strong security policies, data encryption, access control, and protected communications protocols put in place to defend it and other connecting systems.

The potential of incorporating PLCs with Digital Twins technology remains promising, even with the aforementioned limitations. Other technologies like advanced machine and deep learning, artificial intelligence, and AI driven sophisticated analysis enable advanced analytics for optimized decision making on digital twins. Enhanced efficiency predictive maintenance, prescriptive optimizations, and optimization algorithms will be made possible with further development of deep learning, machine learning, and artificial intelligence.

The combination of edge computing technologies with Digital Twins and PLCs will facilitate more efficient collection and analysis of real-time data. This will ensure holistic monitoring, control, and optimization of industrial systems which will subsequently enable semi-autonomous and intelligent operations. Furthermore, greater optimization and insights along the supply chain will be made possible with multi-organization sharing and integrating their digital twins into collaborative digital twin ecosystems. This approach will enhance cross-organizational collaboration, data sharing, and interoperable system marketplaces driving data silos' interoperability.

With the application of Virtual Reality (VR), Augmented Reality (AR), and PLCs, immersive training, visualization, and collaboration will all be possible in conjunction with digital twins. This will enhance productivity from improved maintenance tasks, more effective troubleshooting, and better training due to mitigated downtime. Additionally, the system contactless communication, enhanced perception, task prioritization, and rapid adaptation will be possible with the addition of a human-robot interface [11].

Interoperability, data accuracy, and simplicity of integration will be enhanced with standardization on the combining of digital twins with PLCs. Standards and policies concerning industry practices will permit more fluid intercommunication alongside data sharing with digital twins, PLCs, and all their associated network systems, which would contribute to innovation and cooperation.

To summarize, there is an optimistic outlook for the combination of digital twins with PLCs when considering the imposed challenges. The restrictions posed by analytics, IoT, VR/AR, and standard integrations will actively improve the optimization of industrial procedures, maintenance forecasting, and overall operational efficacy. Organizations willing to confront these challenges alongside embracing changing dynamics are poised for innovative leadership amidst rapid industrial automation advancements.

# 9 Conclusion

This study focuses on the innovative use of digital twins in the context of industrial automation and programmable logic controllers (PLC). The use of digital twins alongside PLCs stands to gain a great deal from operational enhancement, predictive maintenance facilitation, optimization of processes, and innovation proliferation across industries. Digital twins create a virtual replica of a physical system and they offer insight simulations, and analytics while monitoring that help ensembles strategize and enhance their operations.

The examples and scenarios discussed are meant to portray the prospective benefits of digital twin technology at PLCs. Enabling remote control through terminal interfaces sets the groundwork for automation of routine engineering tasks and transforms the contemporary view of maintenance diagnostics while predictive maintenance plans assure maximal equipment activity. Optimizing production processes are among other benefits which could enhance user experience. The field of digital twins is still emergent and relatively new which indicates a great deal of room for growth.

At the same, the application of digital twins to PLC systems imposes some constraints. Planning on these issues in advance will require regimes or solid strategies. These include ensuring privacy and security as well as the integration and regulation of the data quality. Organizations stand to benefit the most from digital twins if they adopt proactive measures towards data management, protective strategies, and robust frameworks.

Focusing on the future, there are abundant opportunities for the use of digital twins in the world of PLC. Further development in the fields of analytics, AI, IoT, VR/AR, and other standards will add capabilities to digital twins and new avenues for optimization and innovation. The development of collaborative digital twin ecosystems and system interoperability will catalyze cross-organizational cooperation and foster unified optimization.

To summarize, the adoption of digital twins in conjunction with PLCs is a bold, revolutionary leap into the future of industrial automation. With the application of powerful real-time data analytics, an organization and its production facilities can achieve unparalleled operational efficiency and process optimization. Meeting the challenges and heading in the directions discussed in this paper will provide organizations with the most value from digital twins integrated with PLCs, ensuring they lead in the shifting industrial paradigm.

With the progress and increased acceptance of digital twins, their influence on industrial automation including the PLC domain will continue to amplify. Accepting such novel technologies enables organizations to usher in remarkable advances in productivity, reliability, and sustainability, giving them a winning edge in smart manufacturing and Industry 4.0.

*Acknowledgement:*
The authors express their thankfulness to the reviewers for their comments and suggestions that improved the presentation of this study.

**Declaration of Generative AI and AI-assisted Technologies in the Writing Process**

During the preparation of this work the authors used Google Translate services in order to improve the readability and language of their manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

*References:*

[1] Thürer M., Li S. and Qu T., *Digital Twin Architecture for Production Logistics: The Critical Role of Programmable Logic Controllers (PLCs)*, in Proc. 3rd International Conference on Industry 4.0 and Smart Manufacturing (ISM 2021), Linz, Austria, 2021, pp. 710-717.

[2] Soori M., Arezoo B. and Dastres R., Digital twin for smart manufacturing - A review, *Sustainable Manufacturing and Service Economics*, Vol. 2, 2023, 100017.

[3] Rantala T., Ukko J., Nasiri M. and Saunila M., Shifting focus of value creation through industrial digital twins - From internal application to ecosystem level utilization, *Technovation*, Vol. 125, 2023, 102795.

[4] Jia W. and Zhang Z., From simple digital twin to complex digital twin part II: Multi scenario applications of digital twin shop floor, *Advanced Engineering Informatics*, Vol. 56, 2023, 101915.

[5] Alphonsus E. R. and Abdullah M., A review on the applications of programmable logic controllers (PLCs), *Renewable & Sustainable Energy Reviews*, Vol. 60, 2016, pp. 1185-1205.

[6] Mellado J. and Núñez F., Design of an IoT PLC: A containerized programmable logical controller for the industry 4.0, *Journal of Industrial Information Integration*, vol. 25, 2021, 100250.

[7] Ricondo I., Porto A. and Ugarte M., *A digital twin framework for the simulation and optimization of production systems*, in Proc. 54th CIRP Conference on Manufacturing Systems: Towards Digitalized Manufacturing 4.0, Patras, Greece, 2021, pp. 762-767.

[8] Tasca L. C., Pignaton de Freitas E. and Wagner F., A study on the performance impact of programmable logic controllers based on enhanced architecture and organization, *Microprocessors and Microsystems*, Vol. 76, 2020, 103082.

[9] Balla M., Haffner O., Kučera E. and Cigánek J., Educational Case Studies: Creating a Digital Twin of the Production Line in TIA Portal, Unity, and Game4Automation Framework, *Sensors*, Vol. 23, 2023, 4977.

[10] Paiva Knebel F., Trevisan R., Santana do Nascimento G, Abel M. and Araujo Wickboldt J., A study on cloud and edge computing for the implementation of digital twins in the Oil & Gas industries, *Computers & Industrial Engineering*, Vol. 182, 2023, 109363.

[11] Giachos I., Paschaliori C., Papakitsos E.C., Drosos C. and Laskaris N., Robotic Sequencing for Intelligent Mission Management, *WSEAS Transactions on Information Science and Applications*, Vol. 22, pp.440-449. https://doi.org/10.37394/23209.2025.22.36

**Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)**

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

**Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself**

No funding was received for conducting this study.

**Conflict of Interest**

The authors have no conflicts of interest to declare that are relevant to the content of this article.