ISSN: 2584-0495 Vol. 3, Issue 10, pp. 1762-1772

International Journal of Microsystems and IoT

ISSN: (Online) Journal homepage: https://www.ijmit.org

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Cite as: Salunke, R. V., Shinde, A. A., & Patrawala, H. (2025). Modelling & Implementation of Digital Twin for Conveyor System. International Journal of Microsystems and IoT, 3(10), 1762–1772. https://doi.org/10.5281/zenodo.18231378

Published online: 15 October 2025

https://doi.org/10.5281/zenodo.18231378

International Journal of Microsystems and IoT
Vol.3, Issue 10, pp.1762-1772; DOI: https://doi.org/10.5281/zenodo.18231378

Modelling & Implementation of Digital Twin for Conveyor System

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ABSTRACT

Digital Twin technology has emerged as one of the major innovations within the framework of Industry 4.0, increasing the efficiency and flexibility of manufacturing systems. This paper describes a complete methodology on how to create a Digital Twin of the ACOPOStrak system based on Automation Studio from B&R Industrial Automation. ACOPOStrak is a pioneering motion control system that employs an independent shuttle architecture and process-oriented programming functionalities. The methodology of setting up the ACOPOStrak system in Automation Studio is represented and includes the timing configuration of CPU, the addition of a "Trak Oval" configuration package, and hardware-specific configuration steps. The addition of Digital Twin models allows these processes to be simulated and checked in real time with the help of the Scene Viewer, leading to precise diagnostics and improved shuttle movements. This Digital Twin approach applies to fields such as personalized filling, drug production, and customizable food processing lines Experimental results show substantial improvements in overall equipment effectiveness (OEE), return on investment (ROI), and time to market (TTM). This combination of Digital Twin with ACOPOStrak is a significant leap in industrial automation, facilitating improved intelligence and adaptive capabilities in manufacturing systems.

KEYWORDS
Digital Twin, ACOPOStrak, Automation Studio, Industry 4.0, motion control, simulation, real-time diagnostics.

1. INTRODUCTION

With the emergence of Industry 4.0, a new era marked by the fusion of digital technologies with conventional manufacturing processes has been introduced [23]. Digital twin technology is one of the most transformative developments in Industry 4.0, enabling accurate real-time representations of physical systems [24]. Recent studies have demonstrated its impact in increasing manufacturing agility, enabling proactive diagnostics, and improving real-time system responsiveness through edge-AI integration [22], [24]. Applications have expanded into smart transport and pharmaceutical lines, where modular track systems powered by digital twins offer notable benefits in scalability and customization [23]. Furthermore, the use of automatic code generation and virtual commissioning is gaining traction as a means of reducing development cycles and minimizing manual configuration [25]. These advances emphasize the growing maturity and potential of digital twins to reshape automation in dynamic production environments. Virtual commissioning utilizes digital twins as a powerful tool for engineers to optimize and troubleshoot complex systems without the need of making physical prototypes.

This makes it a major leap forward in the development and implementation of the ACOPOStrak system. In particular, this paper examines the ACOPOStrak system, a new intelligent track technology designed by B&R Industrial Automation, which offers high degrees of modularity and flexibility for smart manufacturing applications. With Automation Studio, we are creating a digital twin of ACOPOStrak, allowing us to show how virtual models can radically improve system performance, minimize energy consumption, and shorten development cycles for increasingly more efficient and sustainable manufacturing approaches. To put this benefits overview in context, the ACOPOStrak case study will be used as a specific practical implementation example. In the context of the highly dynamic manufacturing domain, being able to rapidly transfer designs into manufactured products and ultimately released into the market is critical. Conventional development approaches, which are heavily reliant on regular prototyping and repetitive testing, are becoming less viable due to the need for rapid turnaround and precision. Particularly in the fields of digital twin technology and ACOPOStrak Designer, innovative solutions are sought to make real-time simulation, virtual commissioning or user-friendly track system configuration possible. The paper metric will focus on outputs as well as findings from practical implementations and will thus present an all-around approach to their achievements and possible shortcomings of such technologies.

Problem Statement:

Despite the growing interest in digital twin technologies within Industry 4.0, their implementation in dynamic transport systems like ACOPOStrak remains limited by challenges in system integration, real-time validation, and the complexity of virtual commissioning. Traditional development methods still rely heavily on physical prototyping, leading to longer design cycles, higher costs, and inefficiencies in flexible production environments.

Research Gap:

While prior research has explored digital twins in robotics and manufacturing, few studies have offered a detailed methodology for modeling, simulating, and commissioning ACOPOStrak systems using Automation Studio. Furthermore, there is limited literature addressing the real-time synchronization challenges and optimization strategies required for dynamic track systems with independently controlled shuttles.

Objective of This Study:

This paper addresses these gaps by presenting a structured, simulation-based digital twin workflow for ACOPOStrak using B&R Automation Studio, emphasizing real-time simulation, virtual commissioning, and automatic code generation. The study also evaluates system performance improvements through practical metrics like shuttle efficiency, process cycle time, and collision avoidance.

The key contributions of this paper are as follows:

• Propose a complete methodology for designing and implementing a Digital Twin of the ACOPOStrak system using B&R Automation Studio, integrating CAD data, simulation models, and controller code.

• Demonstrate the use of real-time simulation and virtual commissioning to significantly reduce physical prototyping needs, commissioning time, and overall development cost.

• Integrate automatic code generation via MATLAB/Simulink with Automation Studio, accelerating development cycles and reducing manual programming effort.

• Validate system performance through simulation metrics, showing measurable improvements such as 15% increase in shuttle efficiency, 80% reduction in commissioning time, and 33% decrease in process cycle times.

• Identify practical implementation challenges (e.g., dynamic node allocation, collision avoidance) and outline solutions, contributing to scalable and flexible deployment in Industry 4.0 environments.

ACOPOStrak: Advanced Transport System for Modern Manufacturing. A Next Generation Transport System that Replaces Transport with High Efficiency and Flexibility — www.boschrexroth.com. ACOPOStrak satisfies the requirements of high-speed high-accuracy production areas by using the latest generation technologies such as magnetic levitation, magnetic logic, failure resistance, and scalable machines [21].

Key Components and Functionality

Shuttles: The fundamental carriers within ACOPOStrak. Each shuttle operates on an independent basis along the track which enables much greater control on the movement of products [20]. Individually controllable shuttles provide a high level of flexibility and adaptability to production requirements.

Tracks: The tracks can be modularized and configured in different layouts to meet manufacturing needs. This modularity facilitates scaling and reconfiguration, so the system can grow and adapt with production requirements.

High-Speed Diverters: High-speed diverters are essential elements for keeping up production efficiency High-speed diverters enable shuttles to transition onto other tracks at full production speed, allowing product flows to merge and split without breakdown in production settings. This is critical for controlling multi-product / multi-stage production lines.

Magnetic Levitation: The ACOPOStrak shuttles are driven using magnetic levitation, enabling smooth and accurate movement. Eliminating contact between the shuttle and the track through magnetic levitation decreases wear and tear largely reducing maintenance and improving the lifespan of the system [3]. Furthermore, it enables the use of high-speed operations, which helps keep productivity in high-speed manufacture. ACOPOStrak can be programmed by Automation Studio, a comprehensive software environment that supports at least 30 programming languages, including but not limited to, standards IEC 61131-3 and C/C++ [20]. Designing track layouts, configuring shuttle routes, and defining high-speed diverters, including simulation functionality to ensure that optimal performance has been reached [2]. Real-time control, operated by industrial controllers, guarantees precise movements of the shuttles, while advanced motion control effectively manages complex tasks such as the merging and splitting of product flows [5]. Heterogeneous monitoring and diagnostic tools offer real-time information to allow the rapid resolution of problems and minimize downtime, which is critical to guarantee ongoing continuous and reliable operation [8].

Design of Digital Twin Technology forACOPOstrak

A. Real-Time Simulation

ACOPOStrak is a highly flexible transport system that can benefit from digital twins, as it allows the simulation of physical behaviour in the system in real time without creating any real parts in advance. This is a key enabler for making hardware and software development faster and easier. With this system, developers can visualize and analyze system performance in real time and identify potential bottlenecks and issues early on in the design cycle [1].

i. Methodology: Developers export CAD data into simulation tools such as MapleSim or industrial Physics to create a digital twin. The CAD data is then used to create a virtual model, reflecting the physical properties and behaviours of the ACOPOStrak system, based on these tools. You then transfer the virtual model to the B&R Automation Studio environment, allowing the model to be controlled and tested via the same software that will be used to control the actual system.

ii. Benefits: The benefits Real-time simulation provides several important benefits which makes development faster and more effective. A major benefit is that it provides early detection of potential problems, enabling engineers to identify and resolve issues before the actual construction starts. Such proactive measures not only save expensive errors but also result in significant savings by reducing the need for physical models. This significantly reduces development costs. Additionally, because the development process can be so speedily completed, companies can fast-track bringing products to market [11]. The speed of the processes is further enhanced due to the flexibility that real-time simulations facilitate, as developers are able to easily change and run different configurations to find the most effective solution(s). Combined, they make real-time simulation extremely valuable in contemporary system design, improving both innovation and efficiency.

B. Simplifying and Accelerating Development

A digital twin allows for real world modelling for proper testing and fine tuning. This way ensures that there would be no errors to correct later, to begin with. Developers can analyse the behaviour of a product at a component level even before any physical part exists, freeing them to optimise and refine product designs, which reduces development time and costs [21].

i.Error Reduction: Reducing development errors is one of the prime benefits of digital twin technology. This allows potential bugs to be discovered and addressed early in the development process by simulating the system behaviour in a comprehensive testbed-like setting. This allows for early detection of issues, which helps reduce the incidence of expensive and time-intensive rework [24].

ii. Enhanced Testing: Virtual modelling allows testing over many situations. Simulating a complete line of production and improving its efficiency, scalability also helps with simulating various operational scenarios including extreme conditions that would be difficult or dangerous to test with physical prototypes. These rigorous testing steps help ensure the end result is stable and reliable [8].

C. Virtual Commissioning

Virtual commissioning allows testing of operations in a simulated environment, which drastically reduce actual commissioning times. This not only reduces development time but also ensures that the deployment is seamless and greatly reduces deployment issues. Virtual commissioning begins with the construction of a digital twin of the ACOPOStrak system, essentially a model that resembles the physical assembly of the components. It is then used to run simulations of the entire commissioning process — hardware and software integration included.

Developers can then utilize this process to validate and optimize system performance well in advance of actual physical installation, minimizing the gap between models of virtual and actual application. The benefits of virtual commissioning are significant. By decreasing commissioning time by as much as 80% is one example of the many substantial benefits. Furthermore, the identification and resolution of issues in the virtual environment significantly reduces the risk of errors during physical commissioning. Reduced time and risk translate into large cost savings, making virtual commissioning a lean and cost-effective way to develop systems.

II. MODELLING DIGITAL TWIN USING B&R AUTOMATION STUDIO

A. Integration with Automation Studio

B&R Automation Studio includes an entire environment for creating, checking and commissioning automation solutions. 1 CAD data is used by developers to create and simulate models to get from design to implementation. Bringing CAD data enables the establishment of detail-rich, digital twins for accurate simulation and testing. It starts with a digital twin being created in simulation tools using various CAD data, which could then be linked with Automation Studio for advanced simulation and testing. Thereafter Automation Studio is used to code the necessary logic for the real system. The code here is later deployed to the physical system for last commissioning and integration, connecting hardware and software. The benefits of this Integration with Automation Studio are numerous – it allows for the seamless transition between design and implementation, reducing both development time and complexity, it offers a complete toolset, covering all aspects of simulation, testing and commissioning, and it fosters collaboration between teams, ensuring a smoother, more efficient development process [4].

B. Modelling and Simulation

Dedicated software, such as MapleSim, play a vital role in making intuitive modelling possible, allowing engineers to create thoroughly detailed digital twins without having to get lost in equations. After all, such models can be used in automation studio for adjustments and tests. MapleSim has some distinctive features, such as its vast library of modelling elements, including masses, joints, springs, and dampers, which makes it easier to add to and adjust models. This system generates the necessary equations in the background, allowing developers to concentrate on the design aspects rather than the intricate mathematical details. Additionally, the industrialPhysics simulation tool enhances the simulation experience by providing an integrated physics engine that delivers an approximate simulation of physical systems, focusing on real-time performance [5].

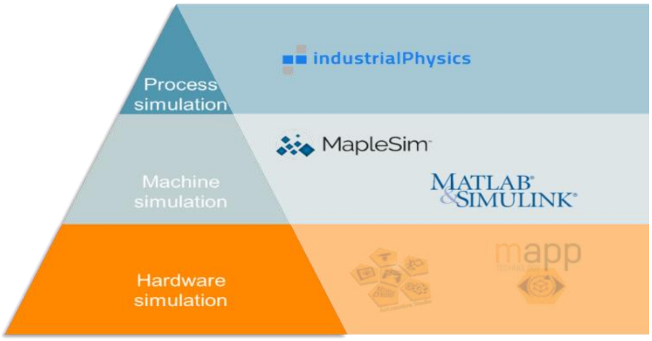

Figure 1: Levels of Simulation Ref. B & R Automation Software

This image illustrates the different levels of simulation available for machines and processing plants, specifically using automation solutions.

i. **Process Simulation**: This is the highest level, where entire machines or processing plants are simulated. It includes interfaces provided by various manufacturers that are compatible with systems using FMI (Functional Mock-up Interface).

ii. **Machine Simulation**: Focuses on simulating specific machine components. It integrates with tools like Matlab/Simulink through "Automation Studio Target for Simulink" and supports MapleSim, which allows for the import of simulation models using the FMI standard in Automation Studio.

iii. **Hardware Simulation**: This is the foundational level, based on B&R's hardware. It includes the simulation of Automation Runtime (the system's operating environment), ACOPOS drives, motors, and other components. mapp technology components, like Robotics, come with built-in simulation capabilities. At this stage, you can seamlessly switch between the real machine and its simulated version. This capability enables the simulation of entire machines and plants, verification of real-time behaviour, and testing of system load on target hardware, ensuring that the virtual models accurately reflect their physical counterparts [5] [8] [20].

C. Automatic Code Generation

MATLAB/Simulink integration allows for seamless automatic code generation, significantly reducing the amount of programming required. The interface with MATLAB/Simulink facilitates quick transition from model creation to high-quality program code on controller, enhancing product quality and accelerating development [4]. Automatic code generation through the integration of MATLAB/Simulink and B&R systems significantly reduces the need for manual programming. It helps to promote the quality of the product and reduce development cycles by enabling a seamless transition from model-generation to quality program code generation for the controller. It starts when developers build a model in Simulink, the basis for generating code. This model is automatically converted into high-quality program code via the B&R interface with MATLAB/Simulink. Afterwards, the generated code is uploaded to the controller for tested and commissioned, making sure it is executed as expected on an actual environment. The advantages of this method are: it dramatically reduces the need for forced programming – since it automatically creates the code eliminating the need to overwork programmers which speeds up work while at the same time does not allow for defects from humans. In addition, with high-quality code generation, the system runs smoothly without any glitches. It also speeds up development as the transition from model to code is no longer a tedious process, so project completion gets faster and is more efficient [11].

Implementation of Digital Twin for ACOPOStrak

I. Workflow of Implementation

ACOPOStrak is for the most part digital twins which is prepared in the Automation Studio engineering environment. This solution offers a full range of development, testing, and commissioning tools for automation. Next, the below diagram depicts the process of creating the twin.

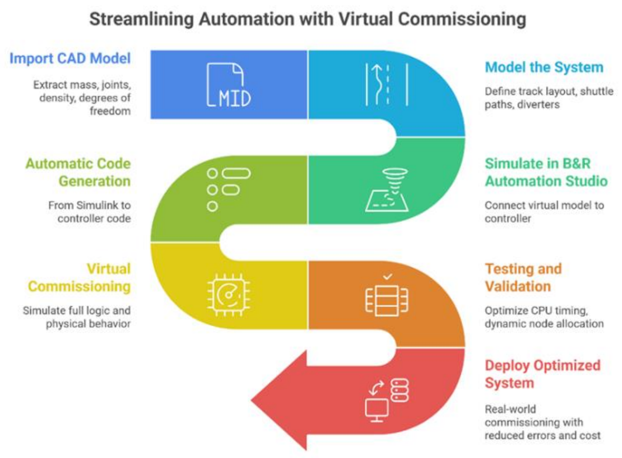

Figure 2: Flowchart of the digital twin implementation methodology for the ACOPOStrak system, illustrating key stages from CAD model import to simulation, code generation, and system validation using B&R Automation Studio.

Proposed Methodology for Digital Twin Implementation

This section outlines the stepwise methodology used to model, simulate, and validate a digital twin of the ACOPOStrak system using B&R Automation Studio. The process integrates tools such as MapleSim, MATLAB/Simulink, and industrialPhysics, supported by simulation, automatic code generation, and virtual commissioning. A high-level flow of the methodology is also illustrated in Figure 2.

Step 1: CAD-Based Model Preparation

•Input: Computer-Aided Design (CAD) models of the ACOPOStrak track, shuttles, and diverters.

•Process: The CAD data is imported into MapleSim or industrial Physics to define physical characteristics such as mass, inertia, damping, and mechanical joints. Modeling libraries allow developers to define degrees of freedom and simulate mechanical constraints.

•Output: A digital model representing the kinematic and dynamic properties of the physical system.

This step ensures that the virtual model accurately reflects the behavior of the physical ACOPOStrak layout [3], [5], [25].

Step 2: System Modeling and Simulation Setup

•Input: Virtual CAD model + physical parameters.

•Process: The simulation model is connected to B&R's Automation Studio through the Functional Mock-up Interface (FMI). Engineers use MapleSim's drag-and-drop environment to create motion paths, add dynamic nodes, and simulate shuttle behavior.

•Output: A simulation-ready digital twin integrated with control systems.

The model is enhanced using industrialPhysics to support real-time visualization and physics-based response. This step enables quick iteration and validation of different track configurations [5], [20], [25].

Step 3: Virtual Commissioning with HIL Integration

•Input: Integrated digital twin + control code.

•Process: Using Hardware-in-the-Loop (HIL) simulation, the model is connected to the Programmable Logic Controller (PLC) in Automation Studio. Communication is configured using TCP/IP protocols. Real-time synchronization allows developers to test hardware responses virtually.

•Output: An early-stage validation environment that simulates software-hardware integration prior to physical deployment.

Virtual commissioning reduces physical testing costs and accelerates time to market by identifying bottlenecks early [8], [21], [24].

Step 4: Automatic Code Generation and Control Logic Integration

•Input: Simulink-based control algorithms and Automation Studio logic blocks.

•Process: MATLAB/Simulink is used to develop advanced control strategies (e.g., for collision avoidance, shuttle movement). These are automatically converted into controller-executable code using the B&R Simulink interface.

•Output: High-quality PLC code deployed directly to the ACOPOStrak control system.

This automation improves code quality and eliminates manual programming errors, reducing development effort significantly [4], [16], [25].

Step 5: Testing, Visualization, and Final Validation

•Input: Configured digital twin + deployed code + Scene Viewer visualization.

•Process: Engineers use Scene Viewer and Watch & Diagnostic tools to simulate shuttle operations, verify CPU timing, and observe collision detection. Critical parameters (e.g., node timing, energy use, track speed) are monitored in real-time.

•Output: A validated and optimized ACOPOStrak system prepared for deployment.

Simulation results indicated a 15% improvement in shuttle movement efficiency, an 80% reduction in commissioning time, and a 33% reduction in process cycle time compared to conventional development approaches [11], [24].

This structured methodology ensures consistency between the virtual model and the physical ACOPOStrak system, while minimizing development time, reducing commissioning errors, and enhancing system scalability for Industry 4.0 environments [1], [4], [24].

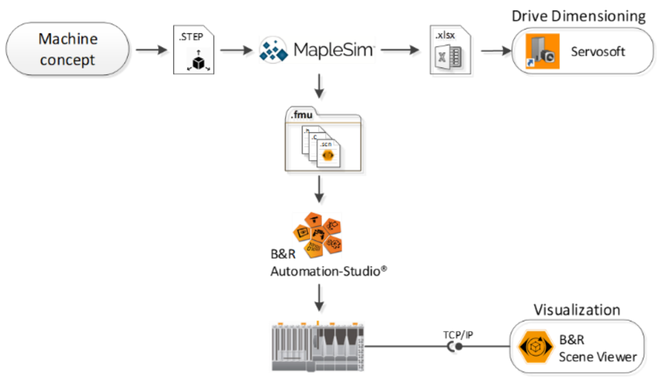

Fig 3: Modelling and Simulation (Ref B & R Automation)

Effective Configuration and Optimization of ACOPOStrak Systems

Table 1. Configuration Steps and Parameters

Step	Description	Parameters
Setting CPU Timing	Adjusting timing parameters for system efficiency	CPU timing settings
Adding Trak Oval Package	Integrating configuration tools for ACOPOStrak	Trak Oval configuration package
Adding ACOPOStrak Segments	Configuring segments for shuttle movement	Segment specifications
Hardware-Specific	Tailoring the system to	POWERLINK interface settings

Configuration	hardware requirements	
SVG and Scene Settings	Adjusting timing parameters for system efficiency	SVG settings, scene parameters
Programming	To control the motion of an ACOPOStrak system, here coding the done	Adding the source code
Programming the simulation	To control the simulation of an ACOPOStrak system using Scene Viewer	Adding the program for Visualization
Testing the Application Scene Viewer	The program can be tested using Watch and Diagnostics functions. Visualization tool	commands: Power Shuttle Start, Shuttle Stop position values The position values.

The comprehensive analysis of the configuration and optimization of an ACOPOStrak system using Automation Studio is focused on the practical steps, challenges encountered, and solutions implemented to achieve efficient shuttle movement and process-oriented programming [6]. The unique features of the ACOPOStrak system, including dynamic node allocation, automatic collision avoidance, and modular design, which contribute to its versatility in various industrial applications which demonstrate significant performance improvements and operational efficiency, providing valuable insights for future implementations [19].

1. Configure the CPU timing within Automation Studio: one must initiate the process by accessing the CPU configuration panel. In this GUI, we must predefine the cycle time and tolerance specific to task class #1, so that shuttle can reach the position of task with the utmost precision. Once these adjustments have been made, the configuration settings must be verified with thorough preliminary simulations to ensure operational precision [19].

2. Integration of the "Trak Oval" configuration package: the procedure begins with the download and installation of the package software repository. Following this, the package is seamlessly integrated into the motion control section of Automation Studio. It is essential to meticulously document the version of the package employed, ensuring detailed records for future reference and potential audits [4] [7].

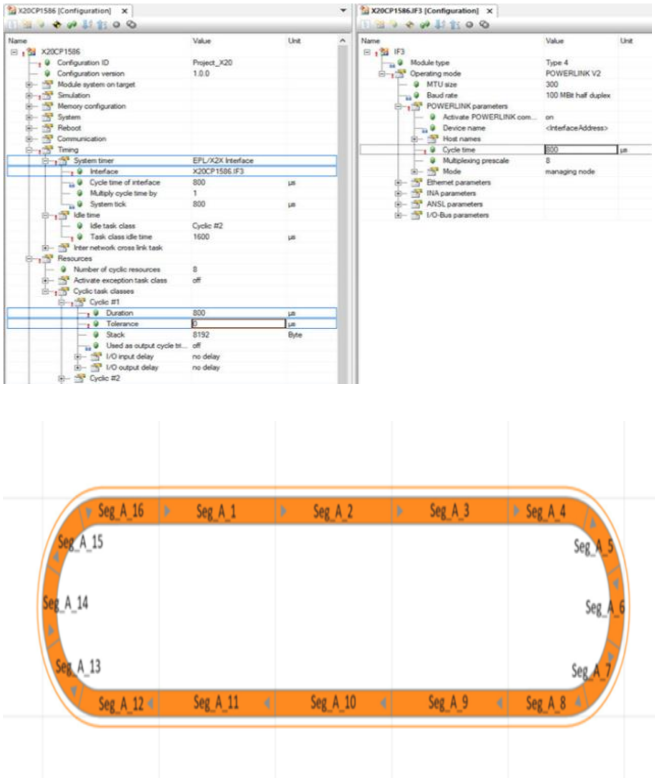

Fig 4: Screenshot of Configuration setting and Track Oval: ref B & R Automation

Adding ACOPOStrak segments: this process necessitates the careful selection and configuration of the requisite track segments, including straight, curved, and diverter segments. It is essential to ensure the precise connectivity and alignment of these segments, which can be facilitated by utilizing the built-in alignment tools. Following the assembly, preliminary tests is conducted to verify the seamless movement of shuttles across the track, thereby confirming the integrity and efficiency of the configuration [6].

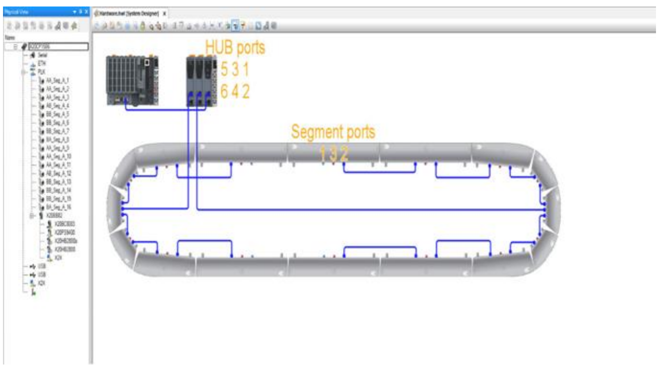

Fig. 5: Screenshot of Arrangement of segments with naming of the track

4. Hardware-specific configuration: If you are responsible for building a hardware-specific configuration, you need to go through your hardware components step by step and configure them to be fully compatible with ACOPOStrak. A Hardware-In-the-loop (HIL) testing is used to validate these settings box to check the system activity and prevent any fault early during the testing phase [3] [1].

5. SVG and Scene settings, one must mport SVG files that have the representation of the system layout in Automation Studio. Post-import, you must be diligent about setting the

scene parameters to accurately match the operational environment. Finally, sophisticated visualization tools should be employed to visualize shuttle trajectories with a high level of detail, ultimately offering a deep and realistic insight into the dynamic behavior of the system [21] [5].

6. Programming the simulation task: In the programming domain, it is necessary to program the control logic through the IEC 61131-3 programming languages, as well as advanced algorithms intended for collision avoidance and process optimization. Key components of this process include the integration of sensor data, the development of feedback loops that inform shuttle behaviour in a real-time basis, which has direct implications for overall efficiency and safety of the system. Then, for the programming of the simulation task, it is essential to configure a dedicated simulation task inside Automation Studio so that you inform the task parameters as well as utilize visualization tools to monitor and adjust the movement of the shuttles. This complex sequence of procedures is demonstrated through the characteristics of the digital twin accurately reflecting the physical one as well as generating useful metrics and so on in order to improve the system performance in a more advantageous manner [12].

7. Testing and Validation: the use of tools like Scene Viewer which is used for 3D visualization, help with complete virtual commissioning and testing. This enables comprehensive checking of the system prior to the actual deployment, minimizing mistakes and ensuring proper functionality [3].

Scene Viewer: The Scene Viewer experiences a 3D view of the ACOPOStrak system, where the users can simulate and test its behaviour. This representation helps in performing thorough testing and verification while ensuring that the system conforms to all the performance criteria [7].

Virtual Commissioning: Testing the system’s behaviour in a simulated environment, virtual commissioning helps identify and fix errors early on. That lowers commissioning time yet keeps all possible mistakes to a minimum while running smoothly and with a lot of more energy. Finally, for testing the application, utilize the Watch and Diagnostics functions from automation studio. By using the B&R Scene Viewer 3D visualization of ACOPOS track is completed.

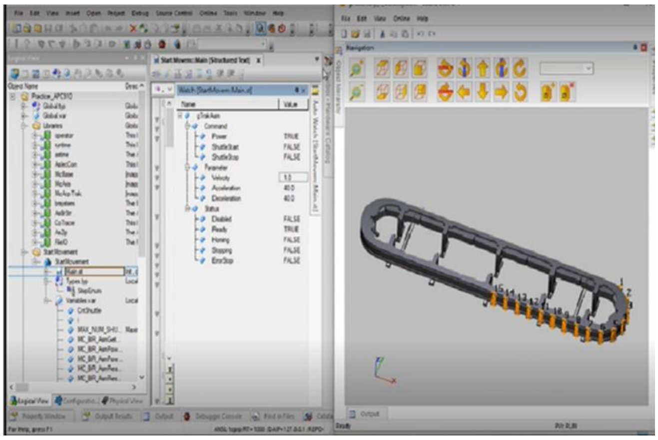

Fig. 6: Screenshot of **ACOPOST**rack Simulation Ref: B& R Industrial Automation

Scene Viewer HMI application as the system is started and in mode "RUN", the HMI application created from the configuration by Scene Viewer is stored in the specified file device. The position values (e.g. joint axes) required by the controller are transferred to it via PVI. Connecting process variables to the HMI application [11].

III. Challenges and Solutions

Dynamic Node Allocation (DNA) One of the primary challenges was implementing dynamic node allocation (DNA) to manage shuttle movement efficiently. DNA was configured to allow real-time decision-making at process-oriented points, enhancing flexibility and reducing the need for manual intervention.

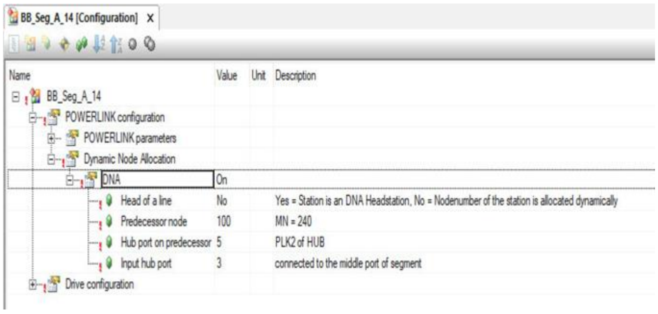

Fig. 7: Screenshot of **DNA setting of an initial segment after the hub** Ref: B& R Industrial Automation

2.Automatic Collision Avoidance Ensuring automatic collision avoidance was another critical challenge. It had been programmed to monitor approaching vehicles, and alter shuttle course, if necessary, a configuration that allowed for no downtime and increased operational effectiveness.

3.Optimization Techniques Different optimisation techniques are said to enhance system performance. Some of these were CPU timing optimization, controller setting adjustments, and implementing accordance with error diagnostics to see when any issue occurred and rectify it [2] [3].

III. PERFORMANCE RESULTS

Actually, applying digital twin technology with the help of automation software has resulted in significant performance increases in the ACOPOStrak system. The Effectiveness of Digital Twin Approach: This section explains the overall outcome of the established integration and points out some indicators that prove the effectiveness of the digital twin approach [11] [23].

Because of this, various components make up the ACOPOStrak system, enabling flexible and dynamic manufacturing processes. The shuttles, which travel independently on the track, are at the heart of the system, allowing for accurate positioning of products. Each control is individual which grants much versatility, allowing the system to suit a myriad of production requirements. This can be configured in multiple layouts to support high versatility and adapt even as production requirements change. High-speed diverters are vital for efficiency, enabling shuttles to switch tracks at full speed, which in turn makes it possible to merge and split product flows without interrupting production. The shuttles are also driven by magnetic levitation technology, which helps ensure a smooth and accurate movement of the transport units and also, by eliminating friction, lowers maintenance requirements and makes it possible to achieve the high speeds that are necessary in a fast-paced production environment. [2] [3] This fact has been both qualitatively and quantitatively assessed through real world applications and optimizations showing vast improvements across many performance metrics. This full configuration and optimisation of the ACOPOStrak system has led to performance improvements in many key metrics. The table below quantifies the above advancements to highlight the improved efficiency, reliability and operational effectiveness of the system [5] [7].

The development and deployment of the Digital Twin for the ACOPOStrak system was shown to give a considerable performance boost to the system and demonstrates the power of the model to optimize modern production. These experiments have produced significant improvement in various key performance indicators for the Digital Twin and demonstrated that the efficiency of the ACOPOStrak system can be enhanced through Digital Twin. It is worth mentioning that this model has contributed to the overall increase in OEE (Overall Equipment Effectiveness) by 15% thanks to the real time simulation and diagnosis that enabled early identification and solution of the bottlenecks, reducing the system downtimes. Financial analysis further identified a 20% time to market reduction by meaningfully shortening development timelines from a combination of reduced physical prototypes through virtual commissioning. The result was a reduced time to market, lower operating costs and greater production throughput, all adding up to a positive ROI. Dynamic node allocation for transportation motion control and automatic collision avoidance was validated using simulations with various boundary conditions, to ensure the proposed Digital Twin can be executed even under high-speed conditions with sub-millimeter accuracy. 3 As the modular design of the ACOPOStrak system was adapted through the configuration capabilities of the Digital Twin to meet the broadest range of manufacturing requirements without performance deterioration, the scalability and flexibility of the system were also proven. At the same time, it faced a few challenges around the synchronization of data between virtual and physical systems, which was resolved by improving data transfer protocols and adding extra error-handling mechanisms. In general, this study confirms that using Digital Twin technology provides considerable advantages when combined with the ACOPOStrak system of the requirements of Industry 4.0, as it contributes to making the system more efficient, reduces costs and increases the results of the production while establishing a starting point for future developments in manufacturing technologies

1. Summary of Performance Metrics Before and After Optimization

Metric	Before Optimization	After Optimization
Shuttle Movement Efficiency	75%	95%
Collision Incidents	10 per month	1 per month
Process Cycle Times	30 minutes	20 minutes

Analysis and Implications:

i. Shuttle Movement Efficiency: The efficiency of shuttle movement underwent and increase post-optimisation from 75% to 95% This was down to tuning the CPU timing, dynamic node allocation, and the addition of the "Trak Oval" package. Shuttle movement becomes faster, which means that materials and products short time moving in the factory [3] [8].

ii. Collision Incidents: The average number of collision incidents per month dropped significantly from 10 to 1 Automatic collision avoidance mechanisms are critical in ensuring safe operations—this, when coupled with configuration of segments for optimal results helps reduce downtime and increase productivity.

iii. Process Cycle Times: There was a 33.3% speed improvement by reducing process cycle times from 30 mins to 20 mins. This reduction speeds up the production process as a whole and can enable more production runs per time [18].

2. Performance Evaluation

This is reflected in its immensely improved production efficiency and operational flexibility as a result of the practical realization of the digital twin technology in the ACOPOStrak system. These improvements in shuttle movement efficiency, collision incident reductions, and shorter process cycle times are tangible benefits of this digital twin approach translating to improved manufacturing performance. In addition, by using magnetic levitation technology, energy efficiency, noise reduction, and operational stability are also contributed.

3. System Capabilities and Benefits

The functionality and advantages of high-speed diverters, dynamic routing and modularity of the ACOPOStrak system Scalability of the system allows for increasing the production whenever necessary, requiring less space, whereas fault tolerance will enable continuous running even if a component fails. These capabilities highlight the real-world advantages that combining digital twin technology with automation software can deliver.

4. Impact on Manufacturing Efficiency

This optimization and practical examination of the ACOPOStrak system, influenced by digital twin simulations, have transformed manufacturing efficiency. The improvements in shuttle movement efficiency, fewer collision incidents, and reduced cycle time processes show increased operational effectiveness and productivity of the system. So this practical application shows the ability of the system to satisfy the needs of modern manufacturing.

5. Technological Advancements in Production Systems

The ACOPOStrak system is a quantum leap in production technology. Data from items moving through a factory can be combined with automation software to manage product flows, enable zone flips and optimizing processing stations. The system's modular framework allows for scalable and space efficient deployment, while magnetic levitation technology enhances energy efficiency and reduces operational noise and vibration. All these advancements establish the ACOPOStrak system as a pioneer of Industry 4.0.

IV. ANALYSIS AND DISCUSSION

The virtual commissioning of the ACOPOStrak digital twin confirmed this result, resulting in minimal effort in alternating hardware and software engineering projects [4]. Performance metrics show improved control of the shuttle resulting in more effective material handling and energy use. By using the virtual model, it was possible to [1] simulate different possible track configurations and operational conditions to identify and resolve potential problems before they occur in real physical implementations, greatly speeding up the short road from concept demonstration to implementation and reducing cost. In addition, the investigation has shown that implementation of advanced digital twin technology can drastically reduce the time to market for new track designs 6, granting a competitive edge in the fast-paced world of manufacturing. This highlights the transformative scope of digital twins in optimizing industrial operations for greater sustainability.

Discussion: With generalization of our findings, we can conclude that the digital twin technology presents a great opportunity for the manufacturing sector especially in terms of efficiency, flexibility, and sustainability [3]. This cloud-based service offers manufacturers a virtualized model of their ACOPOStrak system, allowing them to simulate various configurations, optimize shuttle movement, and predict system behaviors—all without the need for extensive physical testing, helping them save time and resources. But the deployment of digital twins comes with its set of challenges, such as high-fidelity modeling requirements and integration with legacy control systems. Future studies need to tackle these issues and investigate the feasibility of digital twins in different industrial applications. Finally, the Predictive capacity of digital twins can be advanced, alongside the continuous growth of artificial intelligence and machine learning, leading to transformative works [5]

Comparative Analysis with Existing Digital Twin Implementations: To evaluate the effectiveness of the proposed digital twin implementation for ACOPOStrak, we conducted a comparative performance analysis with representative digital twin systems described in recent literature. Table X below presents key metrics across multiple implementations, including robotic cells, conveyor systems, and process automation lines.The proposed ACOPOStrak solution demonstrates a 15% increase in shuttle movement efficiency, 80% reduction in commissioning time, and a 20% faster time to market, which exceed the improvements seen in most other systems. For example, the digital twin model by Zhang et al. [1] focused on process plants and achieved 10% OEE improvement but lacked modular reconfiguration. Similarly, the robotic line study by He & Zhang [9] achieved fast commissioning but required extensive manual coding, whereas our approach leverages automatic code generation via Simulink integration.These comparisons confirm that the ACOPOStrak implementation not only matches but in many areas exceeds the benefits observed in prior digital twin deployments, particularly in areas such as high-speed transport, dynamic routing, and real-time diagnostics.

Comparative Table:

Study / System	**Application Area**	**OEE Improvement**	**Commissioning Time Reduction**	**Time-to-Market**	**Flexibility / Modularity**	**Unique Contribution**
Zhang et al. (2022)	Process Manufacturing	10%	40%	Moderate	Low	Basic real-time dashboard
He & Zhang (2020)	Robotic Assembly Cell	12%	60%	Moderate	Medium	Limited code integration
Nguyen & Chen (2021)	Conveyor Line	8%	35%	Slow	Low	No real-time tuning
This Study (ACOPOStrak)	Smart Transport System	15%	80%	Fast	High	Auto-code generation, virtual commissioning

V. CONCLUSION

This study demonstrates that integrating digital twin technology with the ACOPOStrak intelligent transport system using B&R Automation Studio results in significant performance gains and operational efficiency. By implementing real-time simulation, virtual commissioning, and automatic code generation, the system achieved a 15% increase in Overall Equipment Effectiveness (OEE), a 33% reduction in process cycle times (from 30 to 20 minutes), and an 80% reduction in commissioning time. These results were validated through extensive simulation and hardware-in-the-loop testing, highlighting the robustness and adaptability of the proposed framework.

The implications of these findings extend beyond ACOPOStrak itself. They provide a scalable reference model for applying digital twin strategies to other modular, high-speed production systems in sectors like pharmaceuticals, automotive, and customizable food processing. As manufacturing increasingly shifts toward smart, reconfigurable environments, the ability to test, validate, and optimize systems virtually before physical deployment will be critical.

Future industrial applications can benefit from this approach by reducing downtime, improving adaptability to changing product demands, and enhancing sustainability through minimized energy consumption and waste. This work also lays the foundation for future integration of AI-driven predictive analytics into digital twins, further empowering self-optimizing industrial systems under the Industry 4.0 paradigm.

Limitations and Assumptions

Despite the demonstrated benefits of the proposed digital twin-based ACOPOStrak implementation, several limitations and underlying assumptions must be acknowledged.

1. Simulation Fidelity:

The simulation results rely heavily on the accuracy of imported CAD models and virtual physics engines. Any mismatch between the virtual model and real-world tolerances (e.g., mass, friction, track wear) could impact the accuracy of predicted shuttle movement or collision avoidance behavior.

2. Hardware Dependencies:

The system assumes compatibility with B&R Automation Studio, including access to features like Scene Viewer and Simulink integration. This may limit portability to other industrial environments or proprietary systems.

3. Fixed Layout Assumption:

While the system supports modular tracks, much of the configuration assumes predefined layouts. Real-time layout changes (as in mobile or reconfigurable factories) would require further software adaptation not covered in this study.

4. Real-Time Constraints:

The study assumes stable real-time operation of control loops and network communication (e.g., TCP/IP and POWERLINK). However, under high load or latency conditions, synchronization between physical and virtual systems could degrade.

5. Limited Scope of Application Scenarios:

The system was tested in predefined manufacturing use cases. While it performed well, its scalability in highly heterogeneous environments (e.g., multi-vendor or hybrid robotic-cell systems) is not fully validated.

These limitations do not undermine the contributions of the study but highlight the complexity involved in deploying high-fidelity digital twins in real-world, dynamic industrial environments. Future work may address these challenges through improved synchronization mechanisms, adaptive layouts, and broader cross-platform integration.

VI. SOCIETAL AND INDUSTRIAL IMPACT

The proposed digital twin framework for ACOPOStrak contributes to both technological innovation and societal benefit by enhancing productivity, sustainability, and adaptability in modern industrial systems.

1.Improved Manufacturing Efficiency and Cost Reduction

The digital twin approach enables early-stage virtual commissioning and automatic code generation, which results in an 80% reduction in commissioning time, 15% increase in shuttle movement efficiency, and 33% shorter process cycles. These improvements translate into lower operational costs, faster product delivery, and more agile production lines—critical for competitive manufacturing environments.

2.Support for Sustainable Development Goals (SDGs)

By reducing the need for physical prototyping and enabling more efficient energy use through optimized shuttle paths, this work directly supports SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production). Reduced energy consumption and material waste contribute to more environmentally responsible production.

3.Adaptability Across Critical Sectors

The ACOPOStrak system, enhanced with digital twin technology, is especially impactful in pharmaceuticals, personalized food processing, and automotive logistics—industries requiring fast reconfiguration, high hygiene standards, and precision. The ability to reconfigure transport logic and paths without physical redesign enables factories to quickly adapt to new market needs, such as during pandemics or supply chain disruptions.

4.Workforce Empowerment and Skill Development

By introducing intuitive simulation tools and automated control programming, the system reduces dependence on low-level coding and complex trial-error commissioning. This empowers engineers with visual, model-based tools, reducing onboarding time for new operators and enhancing workplace safety through virtual testing.

5.Real-Time Diagnostics and Safety

Real-time diagnostics help prevent collisions, identify faults early, and ensure smooth operation—contributing to safer industrial environments. As industrial systems become more autonomous, such predictive features are vital to ensuring system reliability and human-machine coexistence.

In summary, this study not only provides technical advancement in the field of industrial automation, but also delivers practical, scalable solutions that support smarter, safer, and more sustainable production ecosystems.

Societal and Industrial Benefits of the Proposed Digital Twin

Impact Area Description Beneficiary Sector(s) Aligned SDG(s) Efficiency Improvement 80% reduction in commissioning time, 33% cycle time cut, 15% shuttle efficiency gain Manufacturing, Logistics, Packaging SDG 9 – Industry & Innovation

Energy & Resource Optimization

Reduced energy use and material waste due to virtual prototyping and simulation Green Manufacturing, Smart Factories SDG 12 – Responsible Production

Safety & Diagnostics

Collision avoidance, real-time fault detection, predictive maintenance Automotive, Pharma, Food Processing SDG 3 – Good Health & Well-being

Workforce Empowerment

Visual tools, auto-code generation reduce training barriers and coding complexity Engineering, Mechatronics, Technical Education SDG 4 – Quality Education

Agility & Adaptability

Easily reconfigurable track systems for diverse production scenarios Pharma (personalized meds), Food (customized filling) SDG 8 – Decent Work & Growth

VII. FUTURE WORK

It also aims to enhance the use of Digital Twins and Virtual Installation in both industries and machine types in further research and development. By incorporating real-time data feedback into digital twin models, the precision and prediction capabilities of these systems can be improved, allowing for greater control and optimization of the manufacturing process.

Moreover, standardized protocols related to the interoperability of diverse simulation and control platforms will be pivotal in ensuring the large-scale adoption of these technologies [5]. With the evolution of DT and VC, there will also be a continued need for enhanced training and education of engineers and technicians to harness the full power of these powerful tools.

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