OTTO-VON-GUERICKE-UNIVERSITÄT MAGDEBURG

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

MB FAKULTÄT FÜR MASCHINENBAU

Faculty of Mechanical Engineering

(M.Sc. Systems Engineering for Manufacturing)

Internship Report

Submitted for the fulfillment of

Mandatory Internship

(September 2024 – February 2025)

at

rexroth A Bosch Company

Bosch Rexroth

Internship Title: Simulation in the Customer Business Factory Automation

Submitted by:

Sooraj Sunil (244087)

Company Supervisor:

Mr. Richard Verbeet

Submission date:

July 2025

Declaration

I hereby declare that all content in this internship report titled “Simulation in the Customer Business Factory Automation” has been taken verbatim or derived from the sources cited, that I have independently completed this report without the assistance of anyone else and that I have not used any sources or tools other than those listed.

This report has not been submitted for any other academic or professional qualification, and I have not previously presented it to any institution or organization. All data and information presented in this report are accurate and authentic to the best of my knowledge.

Magdeburg, 01 July 2025

Acknowledgement

I would like to take this opportunity to express my sincere gratitude to Prof. Dr.-Ing. André Katterfeld, whose expertise, and passion for material handling systems inspired my interest material flow systems and simulation. His guidance coupled with his insightful lectures, and the opportunity to work under him, provided a strong foundation that shaped my understanding in this field. Furthermore, I am deeply thankful to Dr.-Ing. Tobias Reggelin, for enhancing my knowledge and analytical approach in material flow simulations through his 'Modelling and Simulation in Logistics Planning' course.

I am also immensely grateful to Mr. Richard Verbeet, my mentor, for providing me with the opportunity to undertake this internship and his unwavering support, guidance, and expertise in material flow simulation, which significantly contributed to my learning experience. I would also like to express my gratitude to Mr. Ulrich Lindenmayer for his invaluable support during our virtual commissioning exchanges, carefully explaining concepts in this field.

Additionally, I would like to extend my heartfelt thanks to the entire ESP1 team for their direct and indirect support, encouragement, and collaboration throughout my internship. At last, but not the least, I am grateful to Mr. Sahil Tajne for his support during my onboarding process and clarifying my queries.

I sincerely appreciate the guidance, knowledge and support I have received from everyone throughout this internship, which has been instrumental in shaping my technical expertise and professional development.

Table of Contents

List of Figures

1 Introduction

Bosch Rexroth, a Bosch Group company, is a leading provider of automation solutions for industrial and mobile applications, offering cutting-edge technologies that improve efficiency, precision, and sustainability across a wide range of industries. The company specializes in a wide range of products, including assembly technology, electric drives and controls, gear technology, industrial and mobile hydraulics, linear motion technology, mobile robotics, resistance welding, tightening technology, and molding and casting solutions [1]. These cutting-edge systems allow for seamless automation, optimized material flow and intelligent production processes.

In the context of increasing industrial digitalization and the shift towards Industry 4.0, simulation has become an essential tool in the planning and optimization of manufacturing systems. It enables engineers to analyze system behavior, test control strategies, and identify potential issues before physical implementation. Simulation also helps reduce development time, lower costs, and improve the overall quality and reliability of production systems. One of the widely used 3D simulation software tools for modeling and analyzing factory layouts, material flow is Visual Components [2]. Its user-friendly interface and modular architecture make it well-suited for developing digital representations of complex production environments. The software supports robot offline programming, component and process modeling, enabling users to design, simulate, and optimize automation systems efficiently. Additionally, it allows the integration of automation components, virtual testing of control logic, and supports virtual commissioning by connecting with real PLCs and controllers, helping validate system behavior before physical implementation.

During my 6-month internship, I had the opportunity to work with the Engineering Solutions and Projects (ESP1) team, where I contributed to the material flow simulation team by utilizing Visual Components software under the mentorship of Mr. Richard Verbeet. My responsibilities included evaluating and applying Bosch Rexroth's simulation library within Visual Components to develop illustrative models, implementing simulation models for demonstrators, prototypes, and projects, as well as developing and testing components for the Transfer System libraries (TS1, TS2, TS5) and VarioFlow. I also contributed to the design and documentation of demonstrator and training models for the virtual commissioning of technical systems, particularly for the ctrlX-based environment. Additionally, I implemented a proof-of-concept for the operational virtual commissioning of TS2, focusing on signal model evaluation, control logic, and PLC function block integration. This report aims to delve deeply into these tasks, providing a comprehensive overview of the work undertaken and the results achieved.

2 Onboarding with Visual Components

To familiarize myself with Visual Components, I engaged in a comprehensive self-learning program using the Visual Components Academy platform [3]. The initial phase focused on layout configuration, process modeling, and a modelling a basic grasp-and-release robot program. I also developed a simple digital factory system incorporating conveyors, robots, and human operators, focusing on material flow setup, process sequencing, and system optimization.

In the following stages, I explored component modeling learning path to acquire skills to import and prepare CAD data, create parametric conveyors, define component behaviors, and model robot positioners. Additionally, I completed modules on robot simulation and Python API integration to enable offline robot programming and custom logic development. This structured yet autonomous approach gave me the necessary skills in layout design, component and process modeling, robot programming, and virtual commissioning effectively preparing me to contribute to simulation tasks at Bosch Rexroth.

3 Internship tasks

3.1 Sorter

One of the initial tasks during my internship involved designing and simulating an efficient product sorting system within a manufacturing environment using Visual Components. The scenario focused on managing a mixed flow of four distinct product types (A, B, C, and D) originating from four separate sources. Each source produced a random mix of all product types, with an equal probability distribution (25% per type). The primary objective was to develop a system capable of sorting these products such that each outbound conveyor handled only a single product type.

To achieve this, a simulation model was created based on the layout data provided, utilizing Bosch Rexroth's TS2 transfer system. A key aspect of the project involved evaluating and implementing different sorting strategies while considering system performance and cost constraints. Specifically, the sorting system had to balance cycle time (performance constraint) and costs (design constraint).

The development of the sorting strategy involved the integration of decision points along each conveying line within the sorting area, where sorting actions could be executed based on product type and system conditions. System performance and flexibility can be significantly improved by systematically increasing the number of decision points, allowing for more dynamic and responsive product routing. However, while a higher number of decision points reduces queuing and enhances operational efficiency, it also leads to increased system complexity and cost. Therefore, a careful trade-off between cycle time and implementation cost must be considered to ensure a balanced and effective system design.

Three general sorting strategies explored were:

- **Horizontal Conveyors:** The basic configuration of this approach is to have horizontal conveying lines connecting all four conveyors.

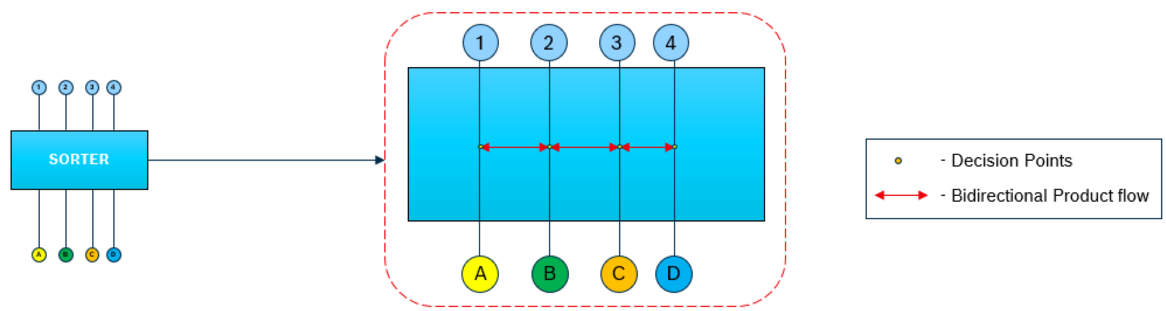


Figure 1: Horizontal conveyor sorter

Products are sorted according to predefined logic implemented at each decision point. While this approach is relatively simple and cost-effective, it may result in reduced system performance due to the formation of long queues at various decision points.

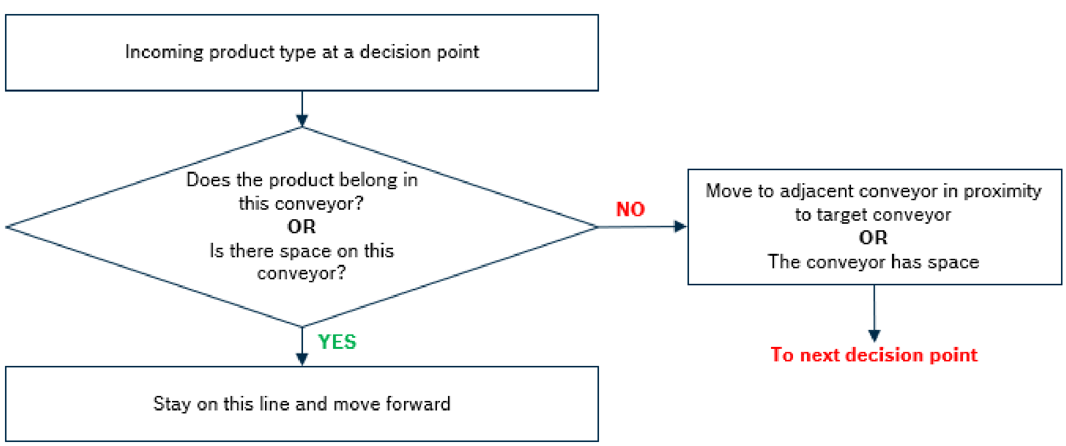


Figure 2: Sorting logic at each decision point

- **Circular Conveyors:** The basic configuration of this approach is to connect all four sources to the circular conveyor.

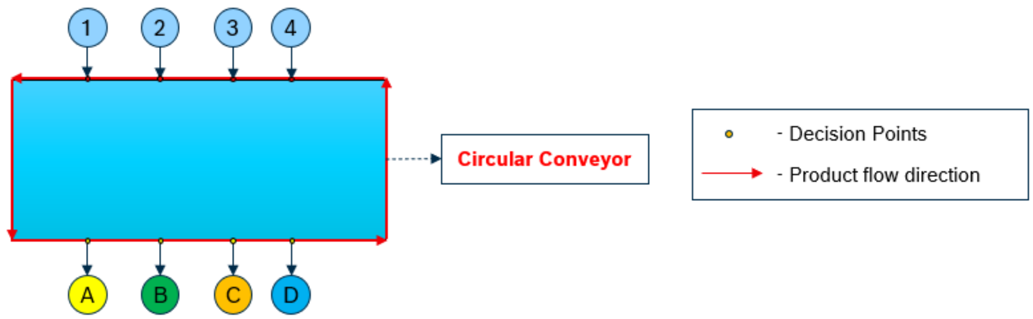


Figure 3: Circular conveyor sorter

The circular conveyor is capable of accumulating, circulating, and distributing products efficiently to the designated output conveyors.

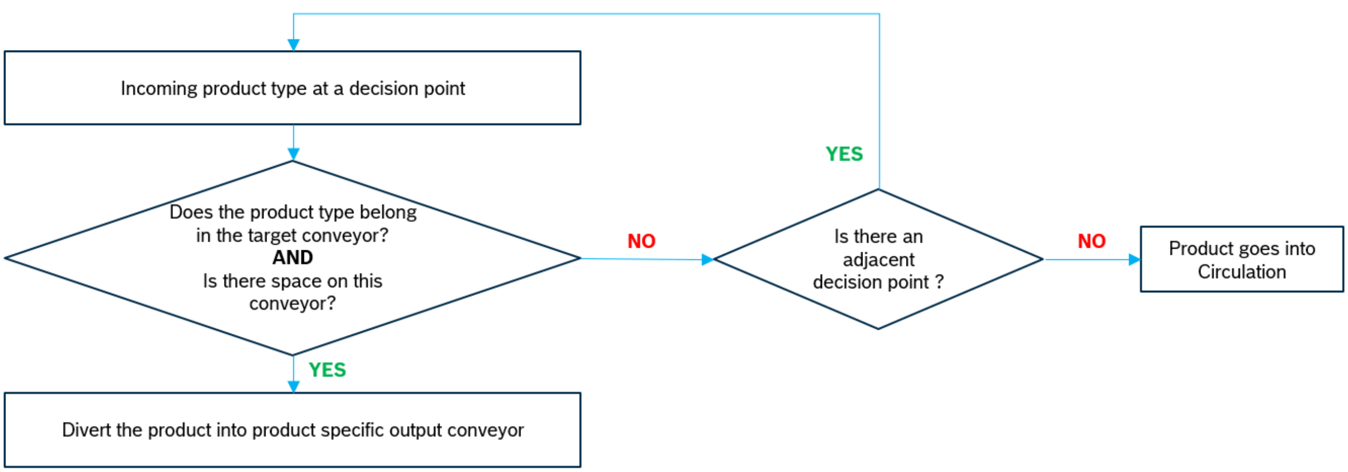


Figure 4: Circular conveyor: Sorting logic at each decision point

The circular conveyor enables the continuous flow of products to the designated output conveyors, enhancing overall system throughput and flexibility. However, this approach may face operational challenges when handling large batches of identical products, as prolonged circulation can lead to congestion and delays in the sorting process.

- **Dead-end buffers:** These conveyors are used to temporarily store and organize products before they are routed to their designated output conveyors. These buffers support pre-sorting operations, allowing the system to manage fluctuations in product flow and reduce congestion during peak loads by holding and releasing products as needed.

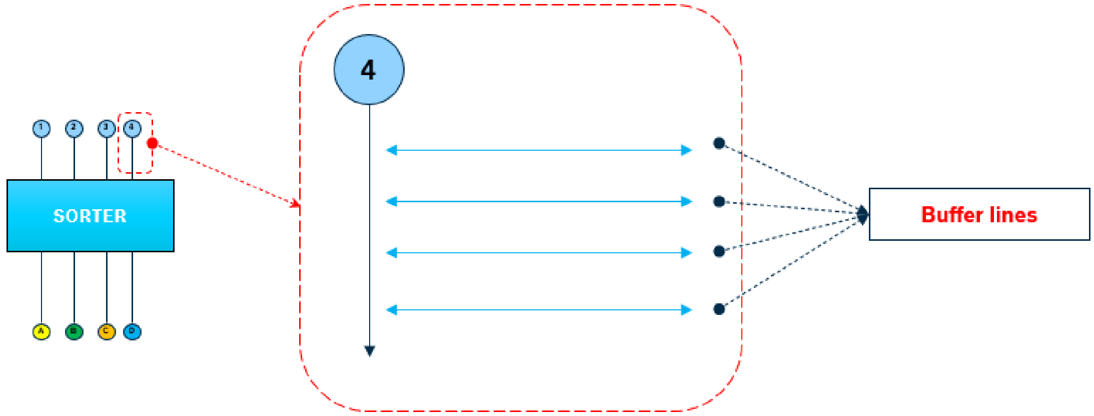


Figure 5: Dead-end buffers

3.1.1 Horizontal Conveyor approach

The horizontal conveyor approach uses decision points and interconnected transfer lines to route products to their target conveyors. By analyzing material flow, potential blockages and queues can be identified and addressed through layout adjustments. A heuristic decomposition approach was applied by breaking down the overall sorting task into smaller, manageable subtasks. For example, product types from sources 3 and 4 were pre-sorted into conveying lines located closer to their respective target conveyors, thereby simplifying the sorting process.

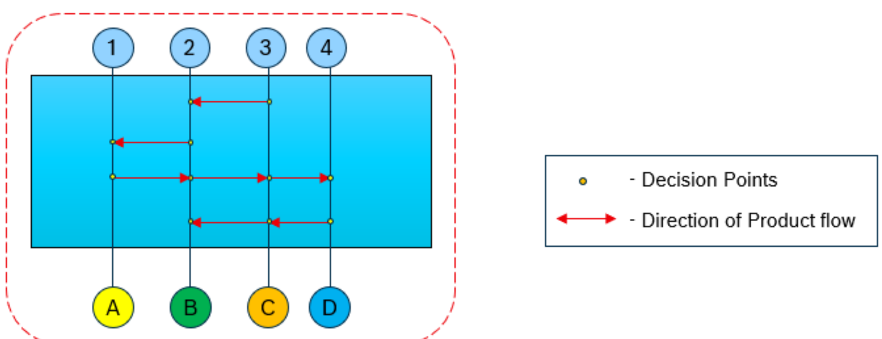


Figure 6: Schematic representation of sorting area

In contrast to a single horizontal line connecting all four conveyors, a waterfall sorting configuration, which includes multiple horizontal conveyors at different levels along the vertical conveyor length, can be implemented. At each decision point, the TS2 Lift Transverse Unit (LTU) simulation object was used to route the product types to the respective conveyors following a product type routing rule.

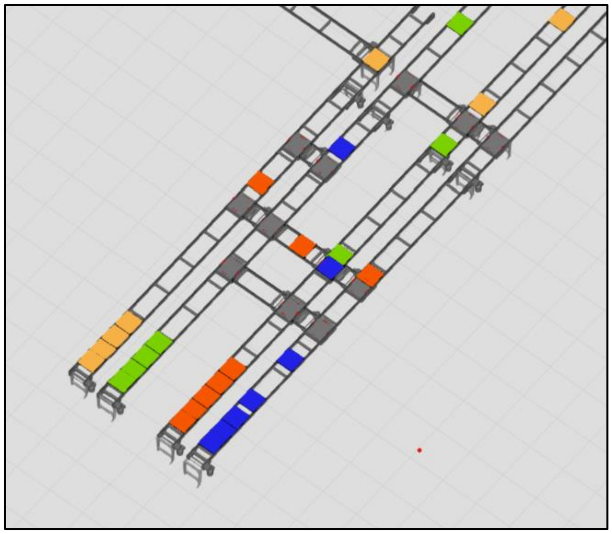


Figure 7: VC Simulation model (Horizontal conveyor approach)

3.1.2 Circular Conveyor approach

This configuration enables the accumulation, circulation, and distribution of mixed product types received from all four sources. The system operates based on a capacity control logic, using simple fill-level control to manage product entry and exit. Sorting decisions are made at designated decision points located at the entrances of the output conveyors. Products are directed to their respective output lines based on availability. If the target line is at capacity, the product continues to circulate until space becomes available. This method enhances flow continuity and allows for dynamic handling of varying product mixes.

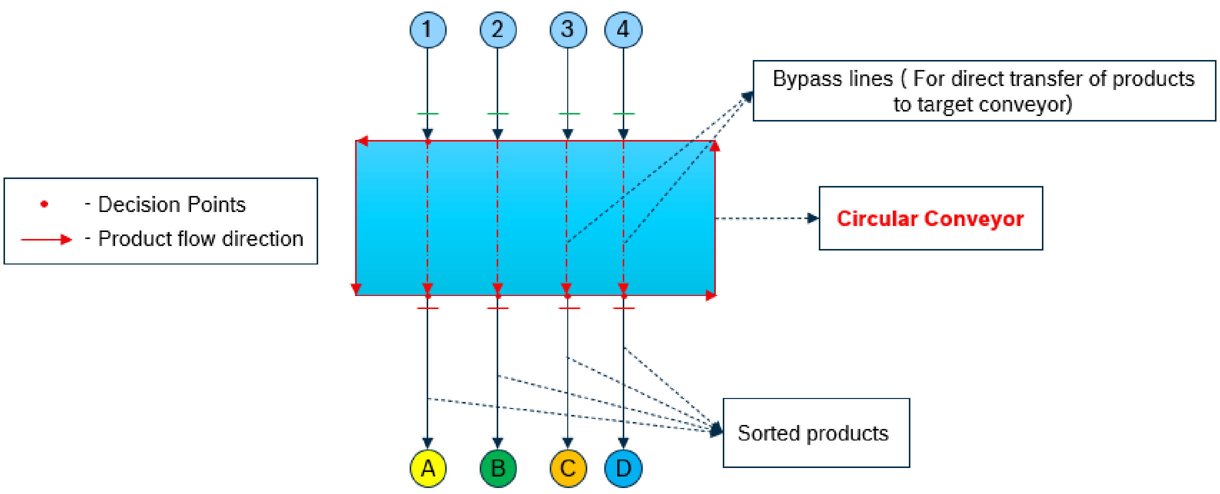


Figure 8: Schematic representation of sorting area

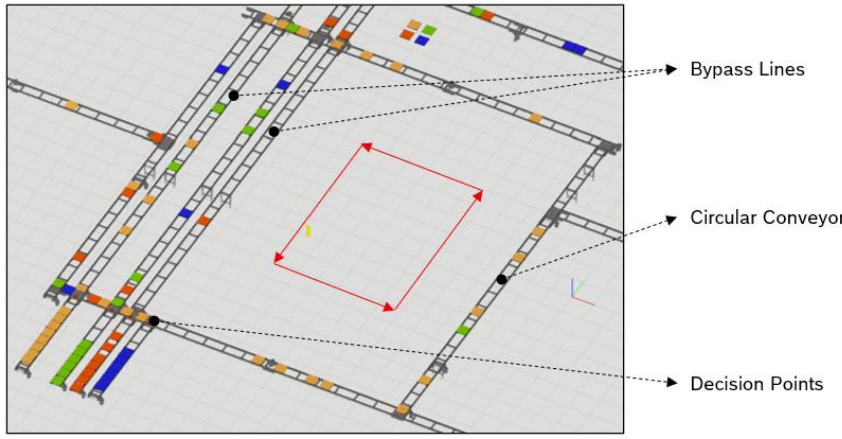


Figure 9: VC Simulation model (Circular conveyor approach)

3.2 TS1 Library development: Component modelling

As part of the Transfer system 1 (TS1) [4] library development, the components to be modeled were first identified through a detailed review of the TS1 product manual. The corresponding CAD models were imported from MTPro [5], Bosch Rexroth’s software used for planning and designing assembly systems, into the Visual Components simulation environment. To improve simulation performance, especially when using multiple instances of the same component, the imported geometries were optimized by reducing the number of triangles and simplifying the models. This included the removal of small holes, hidden features, and unnecessary geometric details using the optimization tools available in Visual Components. After geometric simplification, attributes for e.g. conveyor length, width etc. were defined, and relevant simulation behaviors including sensors, interfaces, and transport paths were added. These enhancements allowed the components to replicate real-world functionality accurately within the simulation model.

- **Belt Section:** Conveyor section with own drive for the transportation of workpiece pallets.

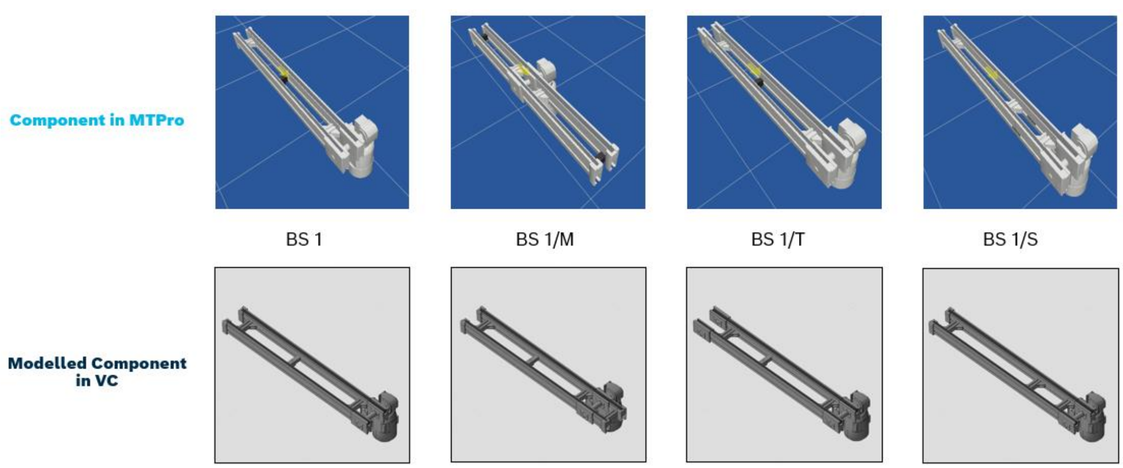


Figure 10: TS1-Belt Section variants

- **Stop Gate:** Designed to stop and separate workpiece pallets on a conveyor, e.g. in an automated station where the actuation is achieved pneumatically.

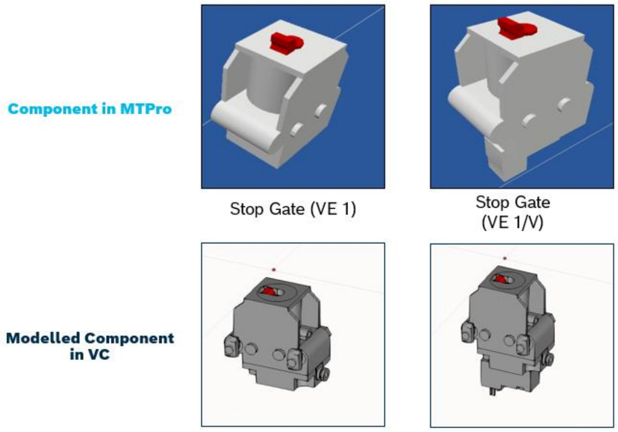


Figure 11: TS1-Stop gate

3.3 TS1 Library development: Component testing

Following the development of the TS1 library components, I developed and executed a systematic testing procedure to validate their functional accuracy and reliability within the simulation environment following the V-model framework for system development. Each component was tested individually and in combination with others to verify correct behavior, parameter responsiveness, and interaction with other library components. The objective of the testing phase was to ensure that all modeled components accurately represented their real-world counterparts and could be released to the public via Visual components e-catalogue and could be seamlessly integrated into complex simulation models.

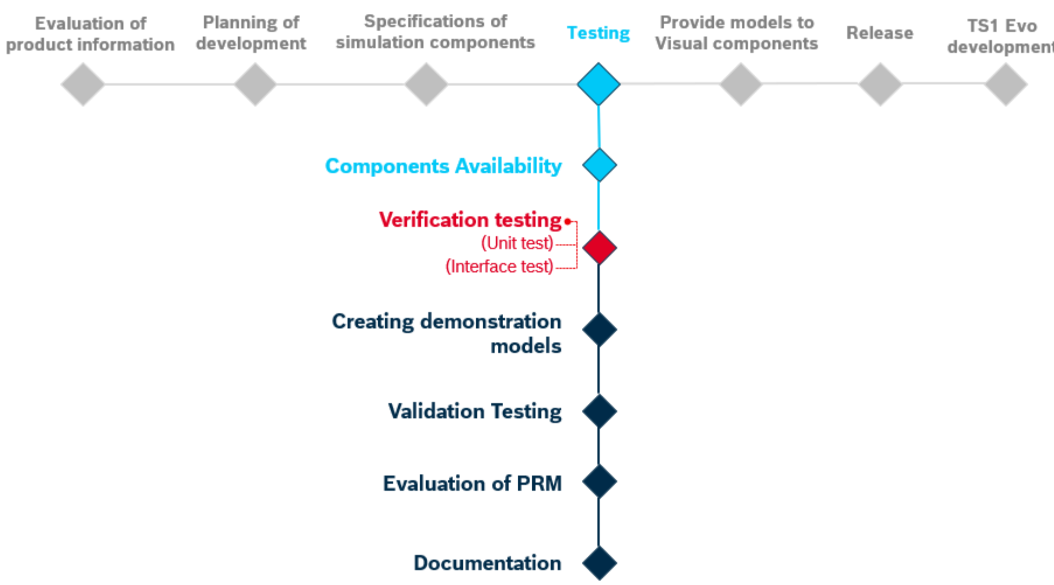


Figure 12: TS1-Library development overview

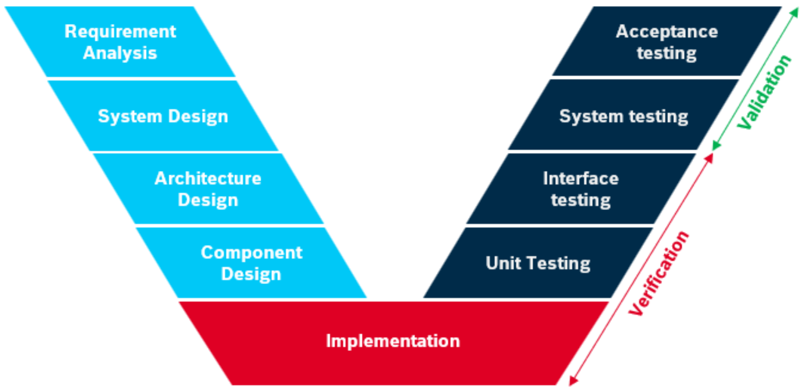


Figure 13: V-model framework for system development to ensure validity

3.3.1 Testing phases

- **Checking component availability:** The first step in the testing process involved verifying if all the components are available for testing by comparing the modeled TS1 components against the official documentation and specifications available in MTPro.
- **Verification testing:**

a. Unit testing (Parameter Validation & Geometric evaluation)

In the unit testing phase, each component was verified to ensure that all associated parameters and attributes were correctly defined and operated within the specified constraints. The property names, data types, default values, and constraints were cross-checked against the specifications provided in MTPro with that of Visual Components. To support this validation, a comparison Excel sheet was created (see below), listing the relevant data for evaluation. Additionally, any geometric changes resulting from parameter adjustments such as modifications to length or width were evaluated to confirm that they were accurately reflected in the 3D simulation model.

		MTPro				Visual Components			
Component	Variant	Property	Data type	Limitation	Default	Component	Variant	Property	Default
Belt Section	BS 1	ConveyorLength	Integer	250 -5000mm	1000 mm	Belt Section	BS 1	ConveyorLength	1000 mm
		ConveyorWidth	Integer	80,120,160 mm	120 mm			ConveyorWidth	120 mm
		ConveyorHeight	Integer		850 mm			ConveyorHeight	850 mm
		ConveyorSpeed	Integer	6,9,12,15,18	12 m/min			ConveyorSpeed	12 m/min
		StandardSizes	String	Standard Size/Individual Size	Standard Size			StandardSizes	*preserve*
		DirectionOfTransport	String	Forward, Backward,Alternating	Forward			DirectionOfTransport	Forward
		BeltSectionType	String	BS 1, BS 1/M, BS 1/T, BS 1/S	BS 1			BeltSectionType	BS 1
		WTWeight	Real	0.5 - 3 kg	1 kg			WTWeight	1 kg
		Motor/Gear	String	without Motor/Gear, with Motor without Gear, with Motor/Gear	with Motor/Gear			Motor/Gear	with Motor/Gear
		Motor arrangement	String	Left, Right	Left			Motor arrangement	Left
		Frequency	Integer	50,60 Hz	50 Hz			Frequency	50 Hz
		Voltage	Integer	400 (+10/-12%), 200(±10%)	400 (+10/-12%)			Voltage	400 (+10/-12%)
		ConnectionType	String	TerminalBox, CablePlug	TerminalBox			ConnectionType	TerminalBox
		MotorMounting	Integer	0,90,180,270 deg	0 deg			MotorMounting	0 deg
		Position	Array(Real)[3]					Coordinates (World)[x,y,z]	
		Rotation	Array(Int)[3]					Coordinates (World)[Rx,Ry,Rz]	
		preserve						ConveyorCapacity	9999
		preserve						Accumulate	True
		preserve						SpaceUtilization	True
		preserve						RetainOffset	True

Figure 14: Unit test: Comparison excel sheet

b. *Interface testing*

Interface testing was carried out to verify that individual components interact correctly with other components within the simulation environment. Components were connected and configured in various arrangements to assess whether their behaviors aligned with expected system functionality. To ensure a systematic evaluation, a question-based testing approach was employed, where each specific functionality of a component was associated with a corresponding test scenario. Multiple functionality questions were defined for each component, and the respective outcomes were documented. The results of this process were documented, serving as a structured reference for validating interface behavior across the TS1 library.

Component	Variant	Sl.No	Functionality question	Test to verify this functionality	Execution Start	Execution End	Result
Belt Section	BS 1	6	Does the conveyor transfer products as intended?	• Model a simple belt section with feeder as shown in Test Model M1. • Verify if products move from one end to the other end of conveyor along the defined path during simulation.	20/11/2024	20/11/2024	Passed
		7	When the product moves on the conveyor, does the product move along the desired path?		20/11/2024	20/11/2024	Passed
		8	Does the speed change upon changing ***ConveyorSpeed*** as intended? (Does it slow down or make the conveyor fast?)	• Using the same Test Model M1,verify if changing conveyor speed changes speed of product transport during simulation. • Start simulation and pause once the WPC reaches the middle of the belt section. • Change direction to backward before starting simulation and verify if flow direction is changing once the simulation starts. • While simulation is running, verify if WPC flow direction is changed when direction is changed.	20/11/2024	20/11/2024	Passed
		9	Does changing ***ConveyorSpeed*** during simulation changes the speed?		20/11/2024	20/11/2024	Passed
		10	Does changing the ***Direction*** changes the product transfer direction?		20/11/2024	20/11/2024	Passed
		11	Does changing ***Direction*** during simulation changes the the direction?		20/11/2024	20/11/2024	Passed
		12	Does the ***ConveyorCapacity*** property limits the conveyor capacity to the set limit?	• Use the same Test Model M1. • For the component, change ***ConveyorCapacity*** to 1. • Run the simulation and verify if the conveyor has only 1 WPC at any instant.	20/11/2024	20/11/2024	Passed
		13	Does checking ***Accumulate*** stops the path when a component is blocked?	• Use the same Test Model M1, add a LTU to the section. • Disable ***Accumulate*** for the belt section . • Set LTU routing to either side of the flow direction to block the path. • Verify if path is disabled when the path is blocked. • Now enable ***Accumulate*** and verify if the path is enabled for material flow.	20/11/2024	20/11/2024	Passed
		14	Does checking ***SpaceUtilization*** allow overlapping of components on the path?	• Use the same Test Model M1, with the LTU in the section. • Enable ***SpaceUtilization*** and start simulation. • Verify WPC components do not overlapp once they reach the LTU. • Disable ***SpaceUtilization*** and start simulation. • Verify if the WPC components are overlapping.	20/11/2024	20/11/2024	Passed
		15	Does checking ***RetainOffset*** turns on the ability of component to retain ist position on er	• In the Test Model M1, Select Feeder. • In PartPosition, Enable ***RandomOffsetEnabled*** to create parts at random offset position from the feeder. • Start simulation. • Verify when ***RetainOffset*** is enabled, the parts retain the offset position when it moves along the conveyor. • Verify when ***RetainOffset*** is disabled, the parts snaps to the line of the path when it moves along the conveyor.	20/11/2024	20/11/2024	Passed
		16	Does entering ***SegmentSize*** define the length of path's segments? (ie, One component p	• Create a model as shown in Test Model M2. • Set second ***ConveyorLength*** to 1000mm and ***SegmentSize*** to 500mm (ie. No. of segments = 2) • Run simulation. • Verify if that in each segment, there is exactly one component at any instant. (Note: *No. of segments = ConveyorLength/SegmentSize)*	20/11/2024	20/11/2024	Passed

Figure 15: Interface test: Functionality questions for Belt section

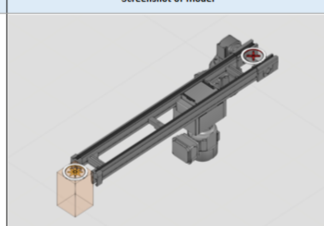
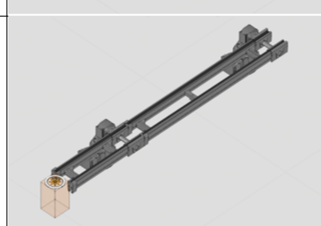
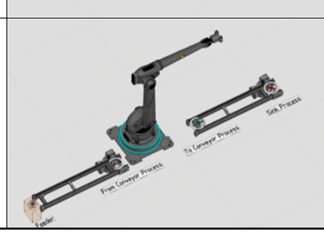
Component Tested	Test Model UID	Screenshot of model	Additional modelling instruction	Test Model (Reference)
Belt Section	M1		• Components used : TS1 Belt section, Feeder, Sink process • Feeder product creation interval : 2sec	Functionality Test Models\01. Belt Section\TS1_Test_models_Combined.vcmx
	M2		• Components used : TS1 Belt section, Feeder • Feeder product creation interval : 5sec	
	M3		• Components used : TS1 Belt section, Feeder, From Conveyor Process, To Conveyor process, Sink process, Generic Articulated Robot, Robot Transport Controller. • Feeder product creation interval : 5sec • Connect Robot with Robot transport Controller. • Define flow from `***From Conveyor Process***´ to `***To Conveyor Process***´using ***Robot Transport Controller*** as ***Implementer***.	

Figure 16: Interface test: Testing simulation models for Belt section

- **Demonstrator Model Creation:**
  Models were created using the developed components to test their functional behavior in simplified use-case scenarios.

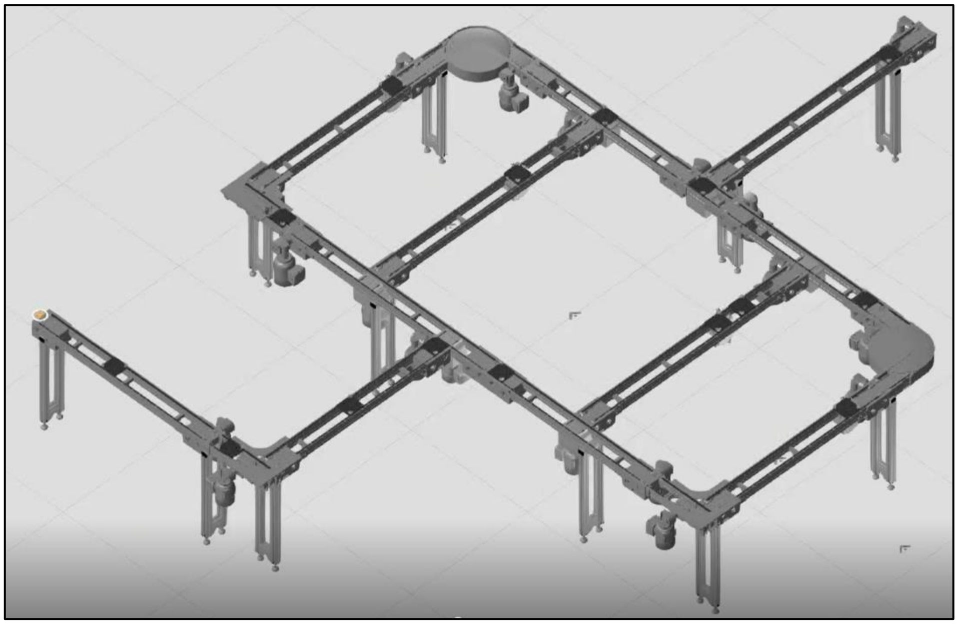


Figure 17: TS1 library demonstrator model

- **Validation testing:**
  In the final testing phase, integrated system level validation was conducted. A complete use-case model was recreated using only the TS1 components from the newly developed library. It helped ensure that the library could support full scale simulation projects without performance or compatibility issues.

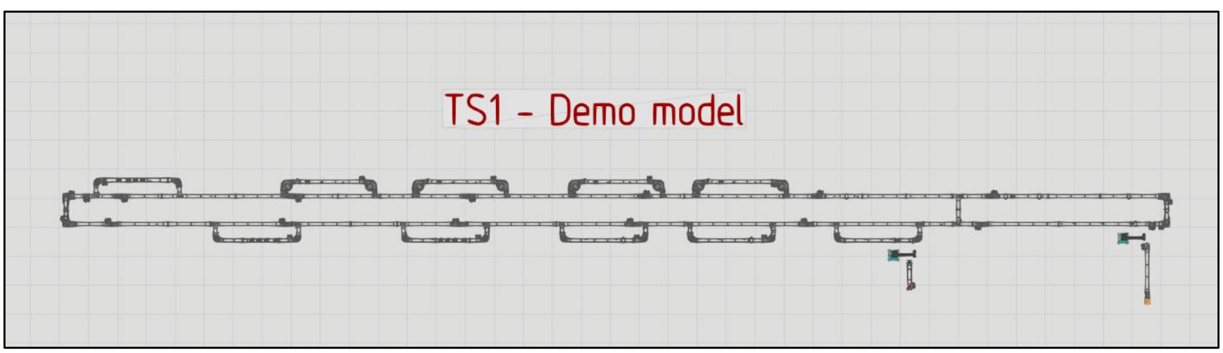


Figure 18: TS1 Components Use-case model (a)

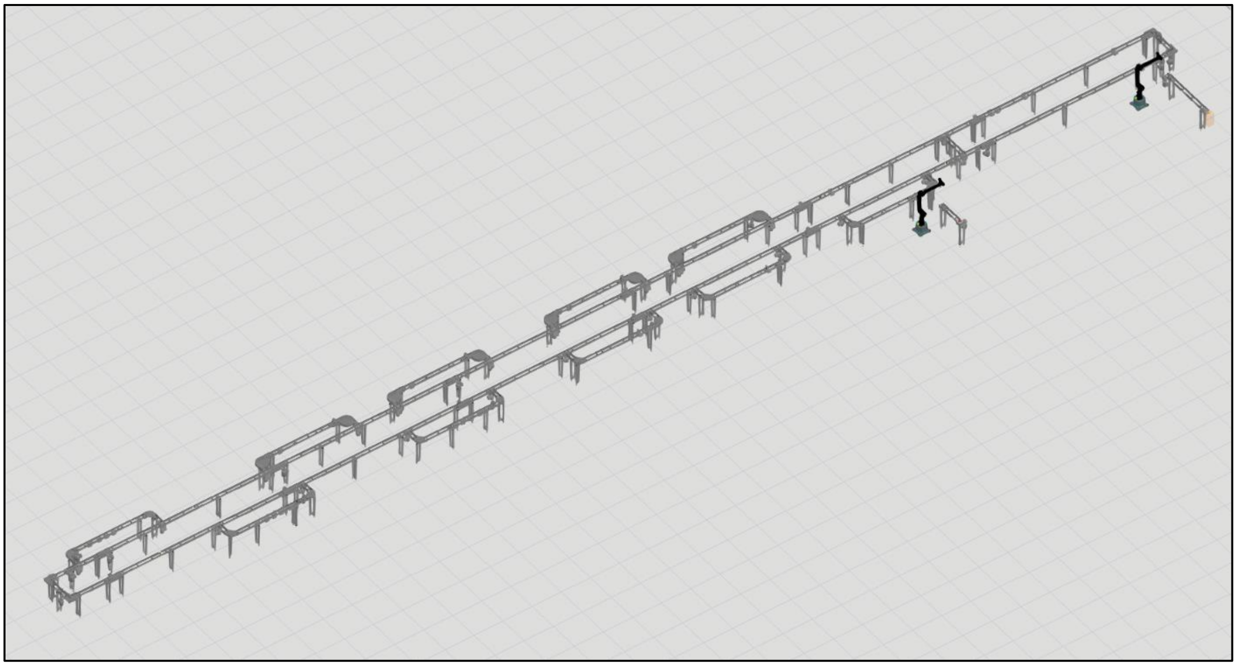


Figure 19: TS1 Components Use-case model (b)

- **Evaluation of Product management:**
  The developed library components were provided to respective product management team for evaluation and feedback. This evaluation ensured that the components met Bosch Rexroth's internal standards and functional requirements before being officially released through the Visual Components e-catalogue.
- **Documentation:**
  In the final phase, findings and procedures carried out throughout the testing process were systematically documented to ensure traceability and future usability.

3.4 VarioFlow Belt Library development: Component modelling

Similar to the TS1 library development, CAD models for each VarioFlow belt [6] component were imported from MTPro, and their geometries were simplified following the same optimization procedures previously described. Key attributes were defined, and appropriate simulation behaviors were integrated to ensure accurate functional representation of the components within the Visual Components.

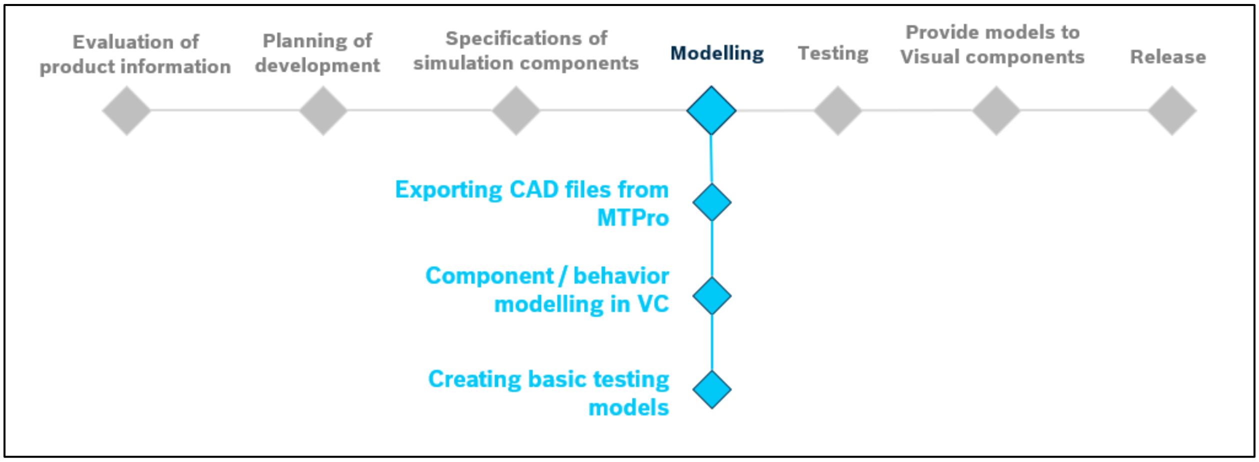


Figure 20: VFBELT library development overview

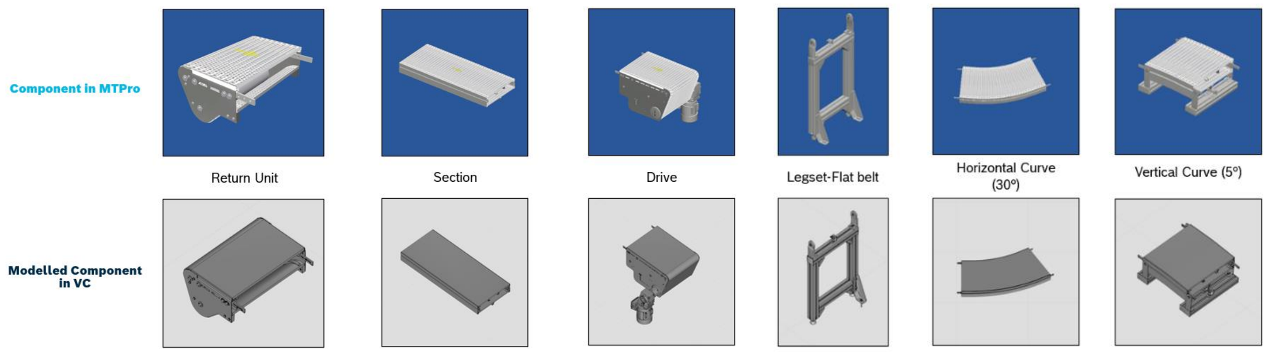


Figure 21: VFBELT library Components

3.5 VarioFlow Belt Library development: Component testing

The testing procedures established for the TS1 library covering component availability, unit testing, interface testing, and validation were applied in the same manner to the VarioFlow belt components. This ensured consistency in the testing procedure and confirmed that all components met the functionality requirements and behavioral requirements.

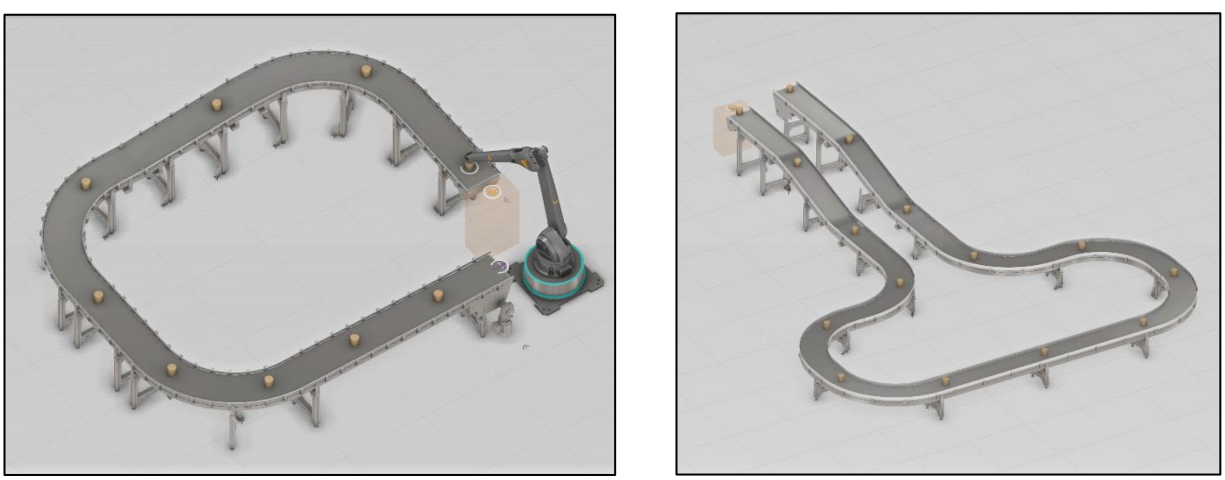


Figure 22: VFBELT demonstrator models

3.6 Design and documentation of training models for Virtual Commissioning

In modern manufacturing systems which are characterized by complexity, the incorporation of innovative technologies is paramount to ensure efficiency, adaptability, and reliability. One such effective strategy for addressing such intricacies is implementation of advanced automated systems, which can identify design and operational concerns at an early development stage.

At present these systems are controlled by Programmable Logic Controllers (PLCs), which face challenges in verifying and validating (V&V) with growing size and complexity of PLC programs. V&V is essential for ensuring the safe and reliable operation of equipment, demanding methods that safeguard personnel, products, and infrastructure. Conventional approaches such as manual debugging or trial and error testing on physical equipment not only pose safety risks but also lead to increased setup times and costs due to their sequential nature in mechanical, software, and commissioning activities.

Virtual Commissioning (VC) offers a more secure and efficient alternative. This simulation-based emulation technique allows engineers to perform V&V activities within a virtual environment prior to the deployment of physical systems. VC enables early testing of PLC programs, evaluation of alternative production concepts, and resolution of integration issues all without the risks and limitations associated with physical commissioning. Moreover, VC facilitates parallel development workflows, allowing programmers to work simultaneously across disciplines. This results in reduced development time, lower costs and risk and faster commissioning while ensuring higher system reliability [7].

A demonstrator model was designed using TS2 components to exemplify the implementation of virtual commissioning via an integration of Visual Components and the ctrlX AUTOMATION platform [8]. The software environment comprised Visual Components for material flow simulation, ctrlX WORKS data layer as data broker, ctrlX PLC Engineering for control logic development and OPC UA as communication protocol. Necessary applications, including ctrlX AUTOMATION PLC and OPC UA Server, were obtained from the ctrlX Store and installed within a ctrlX virtual environment.

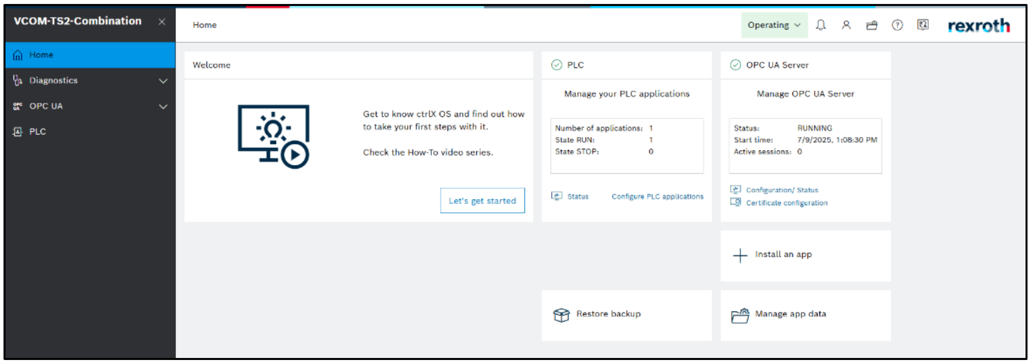


Figure 23: ctrlX WORKS Dashboard

After completion of PLC programming in Structure Text (ST) for the said simulation model, the OPC UA server was configured within Visual Components, and two variable groups were established: Simulation to Server, containing variables sent from the simulation to the PLC, and Server to Simulation, comprising control signals sent from the PLC to the simulation. These variables from simulation were systematically mapped to corresponding variables from the PLC side. The model was then simulated, with the material flow in the simulation being fully controlled by the PLC via signal-based logic. This demonstrated the successful virtual commissioning of the model and validated the functionality of the integrated system. Comprehensive documentation was prepared to guide the setup of the virtual environment using ctrlX WORKS and the installation of automation applications. Additional documentation detailed the configuration of ctrlX PLC Engineering for writing and deploying PLC control code, configuration of OPC UA server and variable mapping.

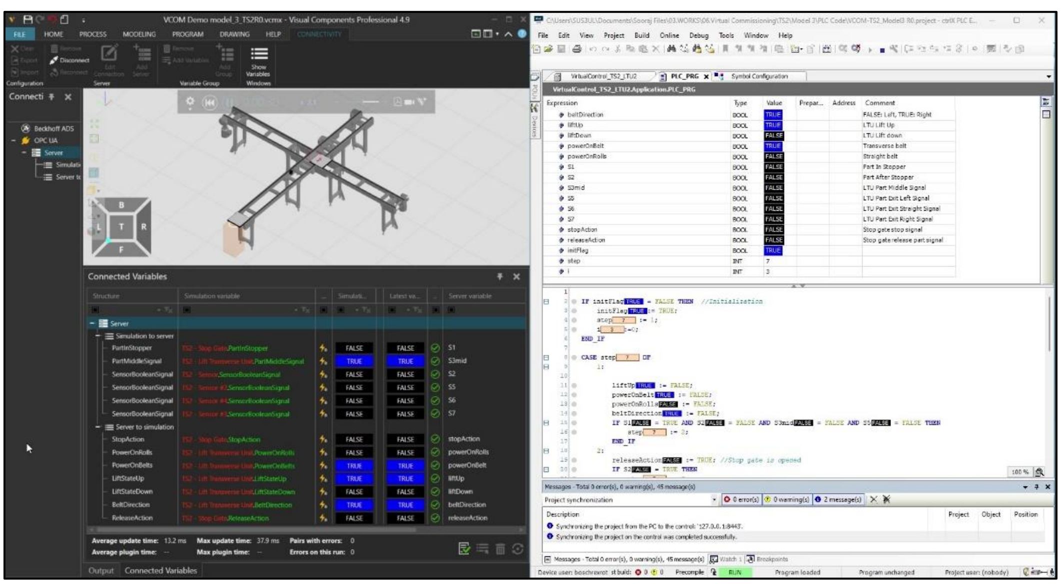


Figure 24: Left-Simulation model with mapped variables, Right- PLC code in ctrlX PLC Engineering

3.7 Development of a Proof of Concept for Operational Virtual Commissioning

The primary goal of this task was to critically evaluate the existing data basis, define an appropriate development environment, and implement a proof of concept for standardized virtual commissioning using configurable operational PLC function blocks within the context of the TS2 Transfer System [9], applied to a range of material flow scenarios. Upon successful implementation of the proof of concept, the framework is to be formalized and extended to address a wider set of standard material flow scenarios, ultimately enabling its application across the complete TS2 component library within the Visual Components simulation environment.

From the available standard function plans defined within the TS2 product catalogue, ‘TFE1: Implementation in transverse section’ for the Lift transverse unit (LTU) was selected for the development. The material flow in this function plan consists of one entrance from the longitudinal section to one transverse exit to the left or right port of the LTU as shown in the figure.

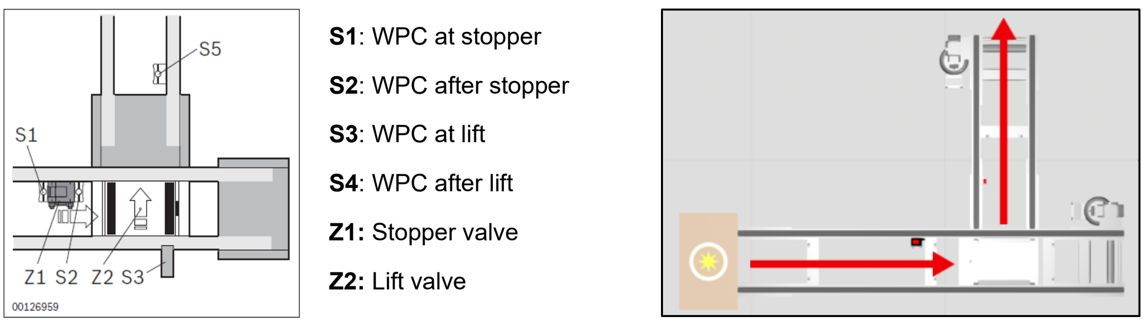


Figure 25: Function plan layout TFE1: Implementation in transverse section

The development process was divided into following subtasks:

- **Development Environment**: Setting up of software environment including virtual ctrlX CORE, OPC UA server and OPC UA interface within Visual Components. The setup and configuration of the software environment has already been established in the previous task concerning design and documentation of demo models for Virtual Commissioning.
- **Analysis of simulation objects:** This subtask involved compiling a list of TS2 components along with their associated variables, properties and signals followed by evaluation of the component’s python script which governs the internal component mechanism.

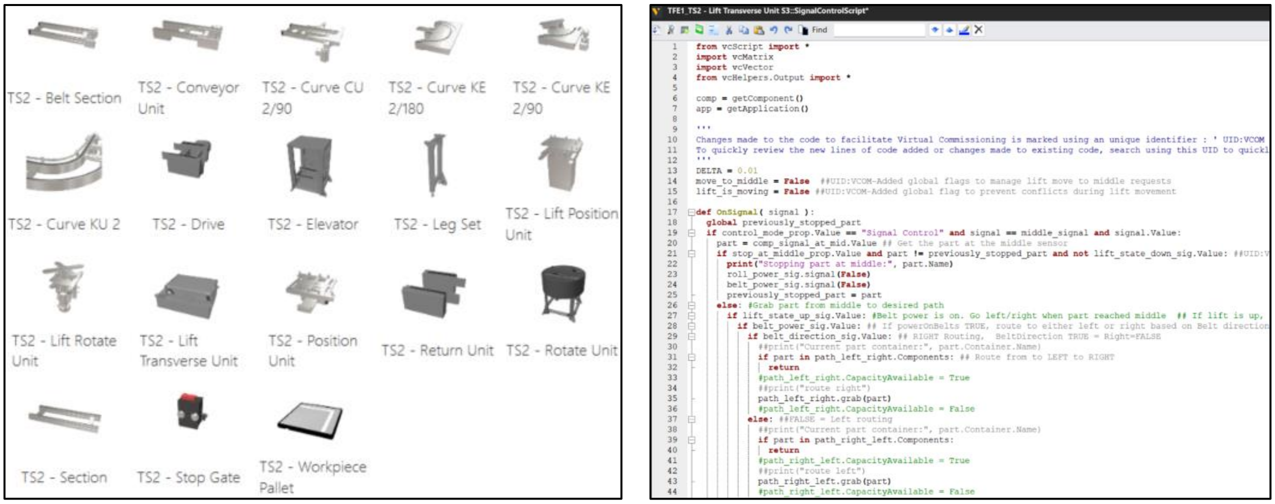


Figure 26: Left: TS1 library components, Right: Lift transverse unit python script

- **Screening product documentation:** The TS2 product documentation was analyzed to define the required input/output (I/O) signals, evaluate the sequence and flow of operations, and examine node variants for both standard and extended configurations. The TFE1 function plan served as the basis for developing the control logic implemented during the PLC programming of the corresponding TFE1 node.
- **Evaluation of Visual components simulation objects:** This phase involved a detailed comparison between the I/O signals and action sequences defined in the product documentation and those implemented within the simulation components in Visual Components. The objective was to ensure alignment between the simulation object's internal component mechanism and real-world system behavior. In this step, the existing Python scripts associated with the simulation components were evaluated, and additional sensor signals and behaviors were implemented to accurately emulate the real-world functionality of the Lift Transverse Unit (LTU) and Stop gate.

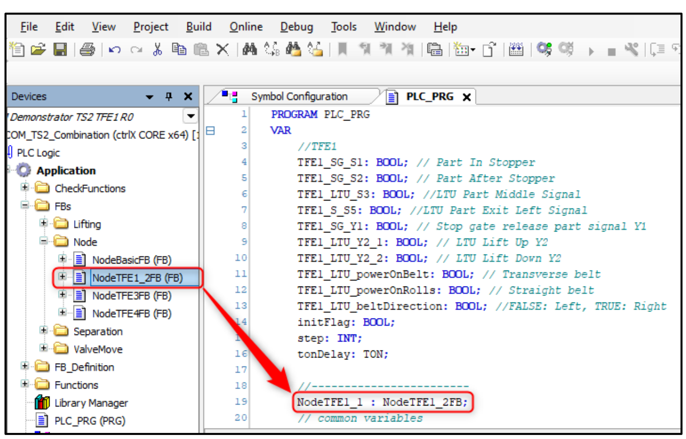


Figure 27: PLC control code with modular Function Blocks (FB)

- **Creation of demonstrator model:** Based on the function plan for Node TFE1, PLC code was developed using configurable function blocks to implement the demonstrator and replicate the defined material flow and control logic within the virtual environment in close collaboration with Mr. Ulrich Lindenmeyer. A demonstrator model for TFE1 was implemented, integrating all previous findings. This model was used to verify the functionality of the defined PLC function blocks in controlling the TS2 components during Virtual commissioning and validating the material flow exactly as described in the selected function plan.

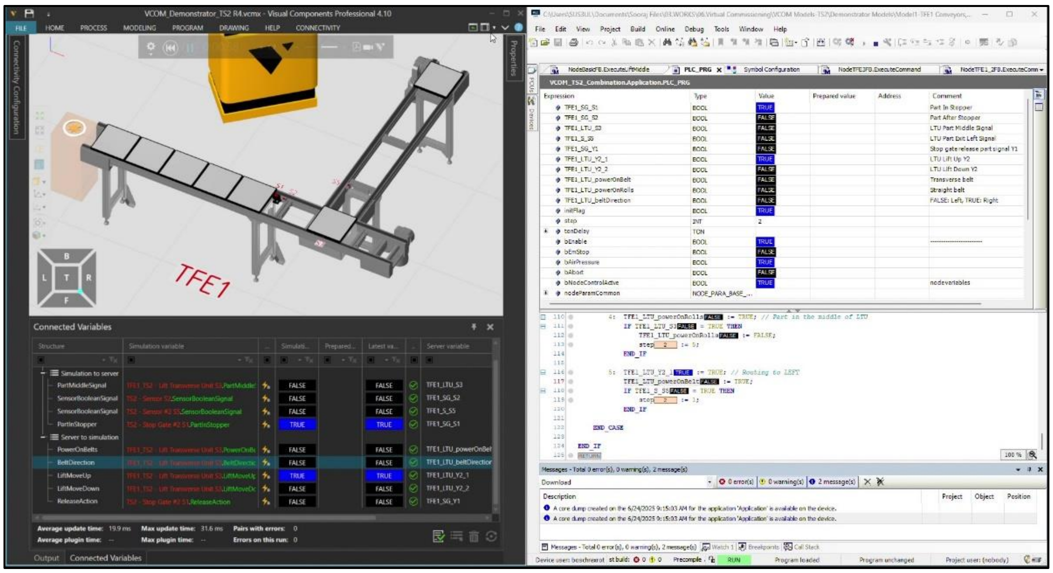


Figure 28: Virtual commissioning: TFE1 node layout

4 Conclusion

This internship at Bosch Rexroth provided me a meaningful opportunity to engage with the practical challenges and technological advances shaping today's manufacturing systems. Through my involvement in material flow simulation, component modeling, and Virtual commissioning, I was able to enhance my technical proficiency in tools such as Visual Components, Python, PLC programming and ctrlX AUTOMATION platform, while enabling the application of academic learning in an industrial setting.

The internship offered valuable insight into how principles of systems engineering are applied in practice. It demonstrated the importance of structured modeling, integration of subsystems, and validation, all within the context of complex automation environments. The theoretical knowledge gained through my master's program, particularly in the course Modelling and Simulation in Logistics Planning, Material Handling Systems and Systems engineering for manufacturing, served as a strong foundation for addressing practical tasks during my internship.

Working as part of a professional engineering team allowed me to experience the value of interdisciplinary collaboration, shared problem-solving, and coordinated execution. Through ongoing discussions, feedback, and joint efforts with experienced colleagues, I developed a deeper understanding of how technical teams communicate and align to achieve common objectives.

In addition, I gained firsthand exposure to the rigorous quality standards, documentation practices, and process discipline upheld at Bosch Rexroth. By following these standards throughout the development, testing, and documentation phases, I recognized the critical role that quality-focused engineering practices play in delivering consistent and reliable solutions.

Overall, this internship bridged the gap between academic theory and industrial application. It strengthened both my technical and collaborative skills and reinforced the importance of systems thinking in developing efficient, modular, and future-ready automation solutions aligned with the goals of Industry 4.0.

5 References

[1] Bosch Rexroth. "Bosch Rexroth Products." https://www.boschrexroth.com/en/de/products/

[2] Visual Components. "Visual Components Software." https://www.visualcomponents.com/de/produkte/

[3] Visual Components Academy. "Visual Components Academy: Learning paths" https://academy.visualcomponents.com/

[4] Bosch Rexroth. "Transfersystem TS 1." https://www.boschrexroth.com/de/de/produkte/industrielle-loesungen/montagetechnik/foerder-und-transfersysteme/transfersystem-ts-1/

[5] Bosch Rexroth. "MTPro Engineering Software." https://www.boschrexroth.com/en/de/products/industrial-solutions/assembly-technology/engineering-software-mtpro/

[6] Bosch Rexroth. "VarioFlow belt." https://www.boschrexroth.com/de/de/produkte/industrielle-loesungen/montagetechnik/foerder-und-transfersysteme/modulbandfoerderer-varioflow-belt/

[7] K. Mykoniatis and G. A. Harris, "A digital twin emulator of a modular production system using a data-driven hybrid modeling and simulation approach," *J Intell Manuf*, vol. 32, no. 7, pp. 1899–1911, 2021, doi: 10.1007/s10845-020-01724-5.

[8] Bosch Rexroth. "ctrlX AUTOMATION." https://apps.boschrexroth.com/microsites/ctrlx-automation/de/

[9] Bosch Rexroth. "Transfersystem TS 2plus." https://www.boschrexroth.com/de/de/produkte/industrielle-loesungen/montagetechnik/foerder-und-transfersysteme/transfersystem-ts-2plus/