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ÓBUDA UNIVERSITY

KANDÓ KÁLMÁN FACULTY OF ELECTRICAL ENGINEERING
ELECTRONIC AND COMMUNICATION SYSTEMS INSTITUTE
INSTRUMENTATION AND AUTOMATION DEPARTMENT

FINAL ESSAY

OE-KVK
2023

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Registration number: T008696/FI12904/K **Neptun code:** [redacted]

Branch of study:
Specialization: Instrumentation and automation specialisation

Thesis title: Automation in Warehousing and Logistics
Task description: Goal of the thesis is investigating warehouse automation efficiency and challenges in adapting to consumer demands and also analyzing the impact of automation on speed and offer insights for businesses in this evolving field.

Institutional consultant's name: Árpád Varga

The limitation period of the theme issued: 31.12.2025.
Deadline for submission of Thesis: 15.12.2023.

The thesis is: Not secreted.

Issued: Budapest, 24.10.2023.

Óbudai Egyetem Kandó Kálmán Villamosmérnöki Kar Elektronikai és Kommunikációs Rendszerek Intézet

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STUDENT STATEMENT

I hereby declare that the present final thesis paper is solely my own work and that the references (written and electronic literature and tools used during the process) have been acknowledged and fully cited. I hereby grant the university and the task assigning institution permission to use free of charge the final results of this paper for their own purposes, abiding by the pertaining rules of encryption.

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AUTOMATION IN WAREHOUSING AND LOGISTICS

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Abstract

Imagine a warehouse that's not just a building with shelves but a place where everything moves like clockwork, super-fast and smart. That's what this project is all about. We're mixing up some amazing tech - like a stacker crane that lifts and moves stuff, a pivot arm sorter that sorts things out, and vision sensors that see everything like eagle eyes.

First up, we'll talk about why making warehouses automated is such a hot topic. It's not just about being cool, it's about making things run quicker, with fewer mix-ups, and way more smoothly. We'll take a fun dive into how a PLC system, the TIA portal, and the Factory I/O simulation make this possible. These are the brains behind the operation, making sure our cranes, sorters, and sensors work together perfectly.

Then, we're going hands-on to talk about the actual gear. How does a stacker crane work? What makes the pivot arm sorter ? And how do those fancy vision sensors do their thing? We'll explore how these pieces are built and the secret programming codes that make them move and work together.

Next, we're looking at how all these pieces - the programming, the simulation, the cranes, and the sorters - come together in a beautiful tech symphony. It's all about teamwork here, and we'll zoom in on how these different parts chat with each other and get their jobs done in the warehouse.

Towards the end, we're going deep into the smart stuff - like planning paths and making the vision sensors turn our stacker crane and pivot arm sorter into a dream team. We'll check out how accurate and fast they are and how well they adjust to different warehouse setups.

This project is all about blending some serious programming smarts with the latest sensor technology. The main thing we want to do is make a warehouse system that is very flexible, very accurate, and just plain cool at what it does. With a little help from those smart sensors, the stacker crane and pivot arm sorter work together like a powerhouse.

CHAPTER 1: Introduction.

In today's dynamic landscape, defined by heightened consumer expectations and the pursuit of swift, tailored deliveries, the role of warehouses and logistics has undergone a profound metamorphosis. Once static repositories, warehouses have evolved into epicenters of a logistics revolution, propelled significantly by integrating automation technologies. These vital hubs stand pivotal in the supply chain, orchestrating the intricate journey of goods from suppliers to end consumers. Among their essential functions lie pivotal roles encompassing receiving, order processing, and seamless product dispatch.

These modern warehouses, whether they are privately owned, rented, or run by a third party, are more than just places to store goods. With high-tech tools like forklifts, racks, and conveyor systems, they make the best use of storage space and make it easy for goods to move quickly. However, a significant transformation is currently taking place: conventional warehouses are gradually giving way to automated facilities.

This transformative process remains incomplete for many businesses that have yet to fully embrace automation within their logistics warehouses. At the same time, competitors who have fully adopted automation point to strong benefits such as lower costs, better worker safety and conditions, and increased warehouse efficiency. As we look into warehouse redesign, this exploration aims to show the diverse logistics automation models available to businesses. [1]

As we look into redesigning warehouses, this study aims to show the different types of logistics automation that businesses can use. There are many different types of warehouses, and each one has its own specific job to do:

1. Warehouses for Raw Materials: These warehouses play an important role as significant hubs for the storage of raw materials that are necessary for manufacturing processes. The strategic location of their facilities and the efficient management of those facilities ensure a consistent supply of materials to production facilities, thereby reducing the likelihood of disruptions.

2. Finished Goods Warehouses: These establishments are responsible for storing the finished products, which are now prepared for distribution to the final consumers. They fulfill the needs and expectations of customers in a timely and effective manner.

Consolidation centers and transit warehouses: These are places where goods come from different places, and they work together to make transportation and distribution more efficient. During the course of their journey through the supply chain, goods can be temporarily stored in transit warehouses, which ensures that transitions are carried out without any problems occurring.

Reverse logistics centers are responsible for handling product returns, recycling, and refurbishing. This is becoming increasingly important as the concept of sustainability gains more attention. They help to lessen the amount of waste produced and increase the level of environmental responsibility.

5. Warehousing in the Public Sector: Warehouses that are run by government agencies or other public entities offer storage solutions for essential items such as public goods, emergency supplies, and other necessities. When it comes to responding to disasters and making sure that essential resources are available, they are absolutely necessary.

This in-depth look will get into the specifics of these different kinds of warehouses, showing how they, each present their own challenges and chances in the changing world of logistics. [13]

Traditional Warehouse:

The traditional warehouses, which have been the standard in the industry for many decades, are distinguished by the fact that their operations are not automated. These warehouses rely primarily on the manual labor of a company's workforce to carry out the tasks that are required on a daily basis. Within the confines of these warehouse configurations, the movement of goods is primarily an endeavor that requires a significant number of workers. The operators carefully transport the items to the designated collection points for the subsequent article picking or to the in-house locations for the purposes of packing and shipping. Despite the fact that manual handling systems are at the center of these traditional warehouses, there are some instances in which there is some limited automation integration. This includes the utilization of fundamental automated tools, such as forklift trucks and conveyor systems, although in rudimentary capacities, with the intention of improving particular aspects of warehouse operations. On the other hand, it is essential to keep in mind that these automation components typically function independently and do not possess the comprehensive and synchronized automation that is characteristic of contemporary warehouse configurations. The heavy reliance on manual labor within traditional warehouses often translates into longer lead times and operational inefficiencies. Within these facilities, the lack of a fully integrated automation system has an impact on both the overall efficiency and the productivity levels of the operations. Because of the inherent limitations of manual handling, this reliance on human effort not only creates operational bottlenecks but also exposes the business to the possibility of human errors.

As technology keeps getting better very quickly, the problems with the way warehouses are usually set up become clearer. It is because of this realization that a significant paradigm shift has occurred within the industry, which has resulted in the development of solutions that are highly automated and driven by technology. These game-changing solutions are redefining the landscape of modern logistics and supply chain management. They offer a significant departure from the labor-intensive practices that are typical of traditional warehousing.

Figure 1 - Traditional warehouse [2]

Semi-Automated Warehouse.

New concepts in warehouse management have led to the development of semi-automated warehouses, which represent a significant advancement in comparison to conventional storage facilities. This modern approach integrates advanced technologies into the operational framework while maintaining a considerable human workforce. At their core, semi-automated warehouses try to take the best parts of both existing automated storage solutions and human expertise and use them together to make warehouse operations better.

AS/RS, which stands for automated storage and retrieval systems, are utilized in these warehouses in a strategic manner. A number of technological advancements, including robotic systems, conveyor belts, and automated guided vehicles (AGVs), are utilized by them. Because they are able to move goods around the warehouse on their own, automated guided vehicles (AGVs) are also very important for increasing efficiency. Automated picking systems have also brought about a change in the manner in which orders are fulfilled by making the picking process both more efficient and accurate. The Warehouse Management System, also known as the WMS, is primarily responsible for this shift. It is the nerve center that is responsible for coordinating the way in which people and machines collaborate. Through the use of WMS, inventory management can be improved by ensuring that items are tracked accurately, that storage is utilized effectively, and that orders are fulfilled in a timely manner. This complicated system makes use of data analytics to assist it in making intelligent decisions that enhance its operational efficiency and reduce the number of errors it makes.

One of the defining characteristics of semi-automated warehouses is the collaboration that takes place between human workers and automated systems. Even though technology can do routine tasks and repetitive tasks, people are still needed for expert knowledge. The workers are responsible for overseeing and managing the computerized systems, intervening in the decision-making processes that are complex, and handling exceptions that require highly accurate reasoning skills.

There are a multitude of advantages that accrue to businesses that adopt this model. Immediate results include a decrease in the number of errors, an improvement in the accuracy of picking, and an increase in the efficiency of operations.

In addition, the hybrid approach, which combines human ingenuity with technological advancements, helps to create a warehouse environment that is more adaptable and resilient. The workforce is given more autonomy, allowing them to concentrate on higher-value tasks, while automation takes care of repetitive operations, which ultimately results in the development of a warehouse ecosystem that is both productive and cost-effective.

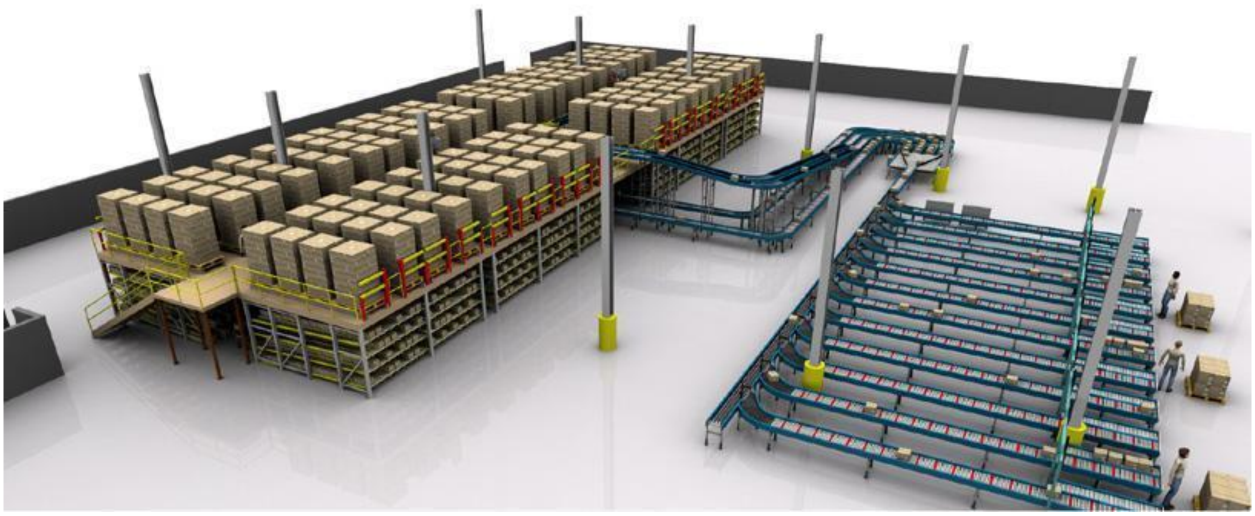

Figure 2 - Semi-Automated Warehouse [3]

Automated Warehouse:

Warehouses that are fully automated represent the pinnacle of technological advancement in the field of logistics management. These warehouses incorporate a comprehensive suite of automated storage and retrieval systems (AS/RS), conveyor networks, and cutting-edge machinery such as pallet stacker cranes and the innovative Pallet Shuttle technology. Using the precision and power of robotics, these facilities are able to orchestrate logistics in a seamless manner, thereby propelling goods through the warehouse in an efficient manner. The utilization of robotic technologies is the most important factor in determining the level of efficiency that these warehouses are capable of. Stacker cranes that are fitted with telescopic forks and are directly integrated with Warehouse Management Software (WMS) are able to navigate the aisles with flexibility and dexterity, thereby expeditiously transporting pallets to the locations that have been designated for them. The logistics flow is optimized, operational costs are reduced, safety protocols are improved, and the customer experience is significantly elevated as a result of this integration. Their remarkable adaptability is what makes these warehouses stand out. They are not solutions that are standardized and can be applied universally. They are, rather, adaptable configurations that are designed to meet the specific operational requirements of each individual warehouse space. This adaptability highlights the significance of tailoring technological solutions to precisely align with the objectives and mission of an organization in order to achieve optimal results. The visual comparison of the conventional manual warehouse with its fully automated counterpart is a powerful demonstration of the progression that has taken place. The reliance on manual labor that is characteristic of traditional setups is contrasted with the technologically advanced and technology-driven operations that are characteristic of fully automated warehouses.

Programmable Logic Controllers, also known as PLCs, are the specialized computing devices that are at the core of this technological marvel. These PLCs have been meticulously designed to function as the brains of any modern warehouse automation system. In the midst of rough industrial conditions, these durable devices coordinate the warehouse's machinery and processes without a hitch. Their meticulously tuned programming manages hardware components and ensures that there is no disruption in communication between the various pieces of equipment, which enables them to facilitate an automated warehouse ecosystem that is both synchronized and efficient.

Figure 3 illustrates an automated warehouse designed using Factory IO specifically for this thesis. The image displays key components such as a stacker crane, racks, rolling conveyors, and sensors, all integral to the warehouse's functionality.

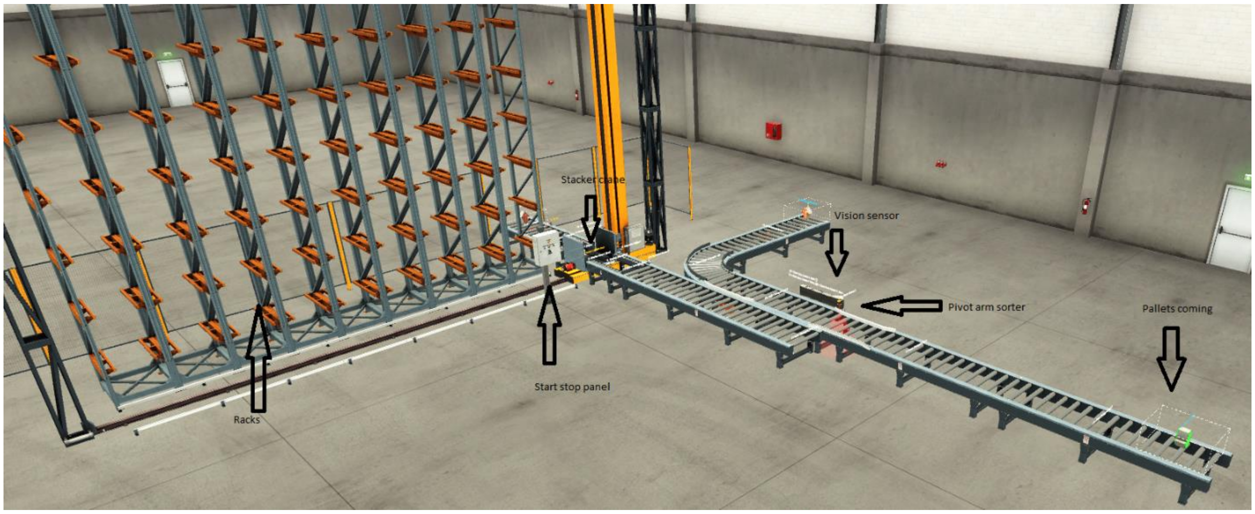

Figure 3 - Automated Warehouse

CHAPTER 2: Core Operations in Automated Warehouses

Warehouses that are fully automated are able to coordinate a wide range of complex operations, which is a reflection of the intricate dance that humans perform within an industrial environment. A warehouse that is both efficient and automated is built on the foundation of these operations. Technologically advanced machinery, such as stacker cranes and conveyor systems, makes it possible for goods to be moved without interruption, which is an essential function of an automated warehouse. These mechanisms speedily navigate the aisles of the warehouse, thereby facilitating the swift transportation of pallets and products to the storage areas that have been designated for them. In the same way that human vision is essential for capturing real-time data on product attributes, sensing mechanisms are also essential. In order to facilitate intelligent decision-making, vision sensors and automated recognition systems are utilized. These systems guide the sorting, routing, and allocation of items within the warehouse layout. It is essential for an automated warehouse to have operations that are capable of sorting and routing efficiently. By repositioning items in a timely manner according to predetermined criteria, pivot arm sorters are able to optimize storage and retrieval operations through precise placement. Sensory input directs these sorters.

One of the most important factors contributing to the overall efficiency of automated warehouses is proper inventory management. Automated systems that provide precise location information and real-time insights into stock availability meticulously monitor inventory levels. This makes it possible to fulfill orders in a well-timed manner. The process of retrieving and storing items is made more efficient through the coordinated operation of various pieces of machinery, such as stacker cranes. These systems navigate the warehouse with dexterity, gaining access to items in a short amount of time and depositing them in predetermined storage locations.

It is essential that these core operations be orchestrated in a seamless manner in order for an automated warehouse to be efficient, precise, and capable of meeting the requirements of modern logistics. This is to ensure that the warehouse is able to meet the requirements of modern logistics. When one investigates automated warehouses beyond the operational complexities that they present, it appears that a number of foundational pillars are responsible for maintaining their efficiency and reliability. This becomes apparent as one continues to investigate automated warehouses. Having robust maintenance strategies in place is essential to ensuring that automated warehouses continue to function without interruption. In order to protect operations from the possibility of disruptions, preventative measures and predictive maintenance approaches are implemented. Additionally, fault tolerance mechanisms are incorporated in order to guarantee that operations will continue without interruption in spite of the presence of unforeseen challenges.

Efforts to optimize energy consumption within automated warehouses include the implementation of energy-efficient climate controls, smart lighting systems, and machinery optimization for the purpose of reducing energy consumption. Through these initiatives, the warehouses demonstrate their dedication to achieving both cost-effectiveness and sustainability.

Ensuring a secure working environment remains a top priority within automated warehouses. Automated operations incorporate stringent safety measures, such as emergency shutdown systems, safety barriers, and comprehensive employee training programs, in order to reduce the likelihood of accidents and ensure that workplace safety standards are met.

Adaptability in automated warehouse design allows for smooth adaptation to fluctuating demands and future expansion. The operations of these systems can be scaled without compromising efficiency or incurring significant reconfiguration costs, which allows them to align with the changing requirements of the business. These systems were designed with flexibility in mind.

Facilitating synchronization with both upstream and downstream components is made possible through the integration of automated warehouse systems with more comprehensive supply chain management frameworks. This synchronization makes it possible to replenish inventory in an effective manner, streamline order processing, and optimize distribution logistics. Waste reduction strategies, recycling programs, sustainable packaging practices, and other environmentally conscious initiatives are included in the initiatives that are focused on reducing the environmental impact of automated warehouses. These initiatives contribute to the sustainability of warehouse operations.

Using data analytics to develop predictive maintenance strategies helps to ensure that machinery is always operational, reduces the amount of time that it is down, and improves overall operational efficiency. Data-driven methods offer insights that support decision-making processes, which in turn optimize warehouse operations.

An automated warehouse is responsible for carrying out a series of meticulous operations that are designed to manage the flow of products and repackage them in an intricate manner. Through the process of breaking down large product quantities into smaller units, it makes redistribution and order fulfillment more efficient. These operations involve a series of processes that are interconnected with one another, including receiving, putting away, order-picking, and checking and packing as shown in the figure 4.

1. Receiving. Receiving notifications in advance of incoming goods is the first step in the process of beginning warehouse operations. The coordination with the activities in the warehouse is optimized through the use of scheduled receipts and unloading within specific time frames. Immediately after their arrival, the products are unloaded with great care, inspected for any inconsistencies or damage, and then staged for the subsequent put-away procedures.

2. Put away. During this stage, scanning is used to register the arrival of the product, assume ownership of the product, initiate payment processes, and ensure that the product is available for customer demand fulfillment. a crucial step preceding product storage, impacting retrieval efficiency and costs. Managing a secondary inventory of storage locations becomes pivotal. In order to efficiently retrieve products for customer orders, scanning records of their locations while they are stored allows for the generation of pick lists.

3. Order-Picking. A warehouse management system (WMS) is used to generate pick lists through the process of triggering essential checks to verify inventory availability. Customer orders are what start these checks. After that, the necessary shipping documentation is prepared, and it is aligned with the activities that are taking place in the warehouse in order to rush the shipment of the product. The optimization of travel and retrieval procedures is the primary focus of this phase, which typically accounts for a significant portion of the costs associated with operating a warehouse.

4. Checking and packing. Although operations are labor-intensive, they require careful handling of each individual item that is part of a customer's order. Checking and packing makes sure that the order is finished and correct, which is an important part of giving great customer service and getting ahead of the competition.

These meticulous procedures, which cover its core operations, significantly increase the efficiency and responsiveness of a warehouse to customer demands. In order to ensure that there is a smooth flow of products and order fulfillment within an automated warehouse, they demonstrate the interconnectedness of each stage as well as the importance of each stage.

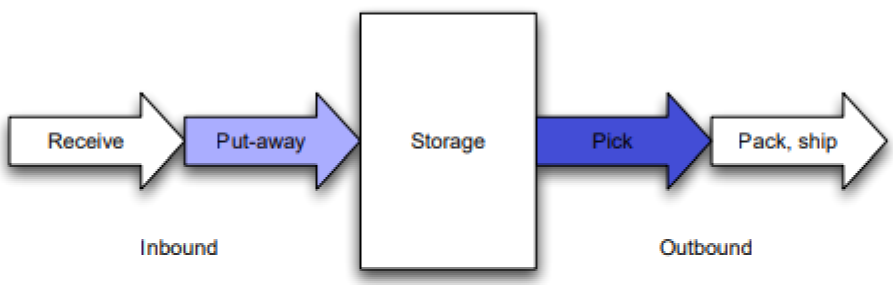

Figure 4 - Inbound and outbound [11]

2.1. Stacker Crane.

In the realm of contemporary warehousing, the stacker crane stands out as the most precise and efficient piece of equipment available. The automated marvels that are operating under the guise of Automated Storage and Retrieval Systems (AS/RS) are equipped with a vertical lifting mechanism that is equipped with telescopic forks. This provides them with a unique degree of agility and speed as they navigate the complex aisles of the warehouse. Without a doubt, the combination of stacker cranes and warehouse management software (WMS) is nothing short of revolutionary. Real-time surveillance and seamless orchestration of the movement and positioning of goods are made possible as a result of this integration, which ushers in a new dawn for inventory management. These systems move pallets from stations for input and output to carefully chosen storage areas tucked away in the maze of racking systems. They work together like a well-balanced technological symphony. This synergy not only maximizes the utilization of space within the warehouse, but it also acts as a cutting-edge force, which increases the effectiveness and speed with which retrieval operations are carried out [5]. Stacker cranes, pivotal in Automated Storage and Retrieval Systems (AS/RS), revolutionize inventory management with their vertical agility and telescopic precision. These incredible machines navigate the warehouse's intricate layout in conjunction with Warehouse Management Software (WMS), which keeps the flow of goods efficient. Their work is a technological symphony that makes better use of space and speeds up the retrieval process. This integration not only makes the storage strategy easier, but it also speeds up throughput, making it the cutting edge of warehouse logistics. These kinds of systems are necessary in modern warehouses because they set new standards for keeping track of inventory and running operations more efficiently.

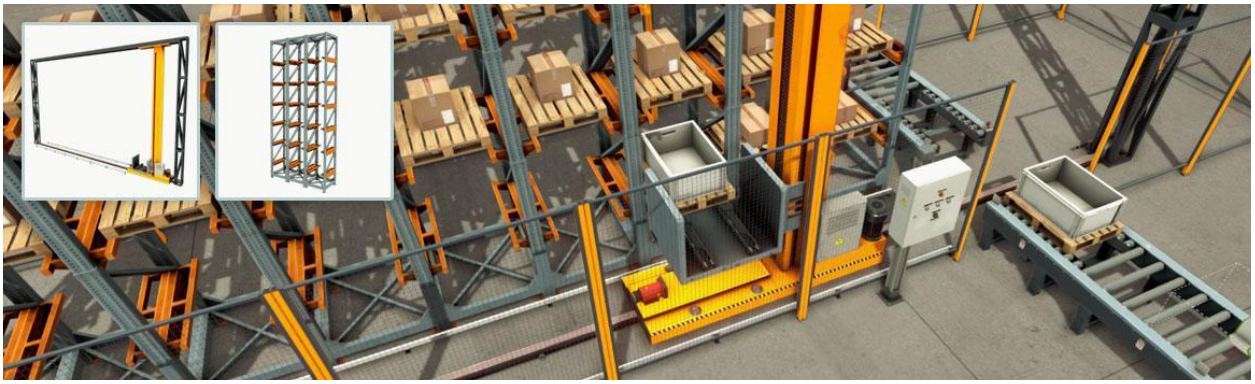

Figure 5 - stacker crane and rack [9]

And here is the stacker crane and the rack that used in this thesis (figure 9) . A rail-mounted stacker crane is used to stock heavy cargo. This product comes with a cart, a vertical platform, and two forks that can slide to either side of the platform. Both the cart and the platform are equipped with two laser rangefinders, which have been positioned to determine the horizontal and vertical position of the platform. Steel racks are upright frames made of steel that are connected to one another by horizontal steel beams. Racks are used to store loads. The type of rack that is currently available is a single-deep rack, which is also referred to as a selective rack. This type of rack only permits loads to be stored one pallet deep. There is a storage space on both sides of the rack for the loads.

The stacker crane will only stop in the right place if each rack is lined up with one of the rail ends. Based on the configuration chosen, the stacker crane can be controlled by Digital, Numerical, or Analog values.

- Forks stroke: 1.2 m
- Cart stroke: 10.5 m
- Platform stroke: 6.625 m
- Cart speed: 1.4 m/s
- Forks speed: 0.5 m/s
- Platform speed: 1.7 m/s
- Number of cells: 18

2.2. Conveyor Systems.

Material handling is a very important part of warehouse operations because it makes sure that everything from raw materials to finished goods moves quickly and easily. Moving goods around in the warehouse to get the most out of its operations is an important part of this process. Traditional methods relied on moving things by hand, but these days, warehouses are using machines like cranes, forklifts, and especially conveyor systems. These automated systems are unique because they can move things mechanically, which means that a lot less work needs to be done by hand. According to the Material Handling Institute of America, this shift is in line with their focus on speed, accuracy, and low cost. The products that conveyor systems move do not change directly because they are an important part of this transformation. Instead, they are very important in supporting the overall cost and effectiveness of warehouse operations. Transporting goods by hand is dangerous in some situations, so conveyors are used to speed up processes, make workplaces safer, help workers be more comfortable, boost output, lower costs, and provide multiple routing options for smart workflow management.

But the real costs of conveyor systems are higher than the price of the parts. The total cost of ownership includes things like installing the mechanical and electrical parts, connecting them to IT systems like enterprise resource planning or warehouse management systems, teaching operators and maintenance staff how to use the equipment, regular maintenance, spare parts, and maybe even maintenance contracts. Some people might not think these costs are important for smaller conveyor setups, but as the system gets more complicated, they do become more important. When it comes to automating warehouses, conveyor technologies are the most important parts because they make sure that goods are moved without any problems. These systems are made up of belts, rollers, or automated carts that keep moving things all the time. This gets rid of bottlenecks and generally makes operations run more smoothly. Some examples of advanced conveyor technologies that can be changed to fit a lot of different warehouse tasks are belt sorters and merge conveyors. They are an important part of the distribution and sorting processes that happen in warehouses. These systems can handle a wide range of load capacities and can be changed to fit different product sizes. The fact that they are used in warehouse automation shows how constantly new things are being developed in this field. This shows how important conveyors are in today's logistics world. [6] Here we have the heavy-duty roller conveyor that (figure 6) , depending on the setup chosen, is controlled and operated by digital and analog values in this thesis.

- Roll Radius: 0.046 m
- Available lengths: 2, 4 and 6 m
- Maximum conveying speed: 0.45 m/s (digital); 0.8 m/s (analog)

Figure 6 - Roller conveyor [9]

2.3 Sensing and Recognition.

When it comes to the world of automated warehouses, sensing mechanisms play an important role that is comparable to that of the senses in humans. They are very important for keeping track of inventory in a smooth and effective way. Vision sensors and advanced recognition systems are very important in this field because they keep an eye on the work. You can get a lot of real-time information from these kinds of systems about a wide range of product characteristics and the environment that these products are in. This information is the basis for the smart decision-making processes that happen inside the warehouse. Vision sensors are very good at gathering important data because they use cutting-edge imaging technology on them. The can pick out very specific traits, like size, color, and shape, with tremendous accuracy. This data is very important for performing complicated tasks like sorting items, finding the best ways to move them around the warehouse, and putting them in the right places.

With the help of automated recognition systems, this data can also be utilized to make informed decisions regarding the transportation, storage, and retrieval of goods. Not only does this improve workflow efficiency, but it also guarantees peak performance from the warehouse's operations. Warehouses have the potential to significantly improve their ability to meet various operational needs in terms of speed, accuracy, and efficiency by making good use of this technology.[7] And here you can see in the figure 7 the vision sensor that used in this thesis.

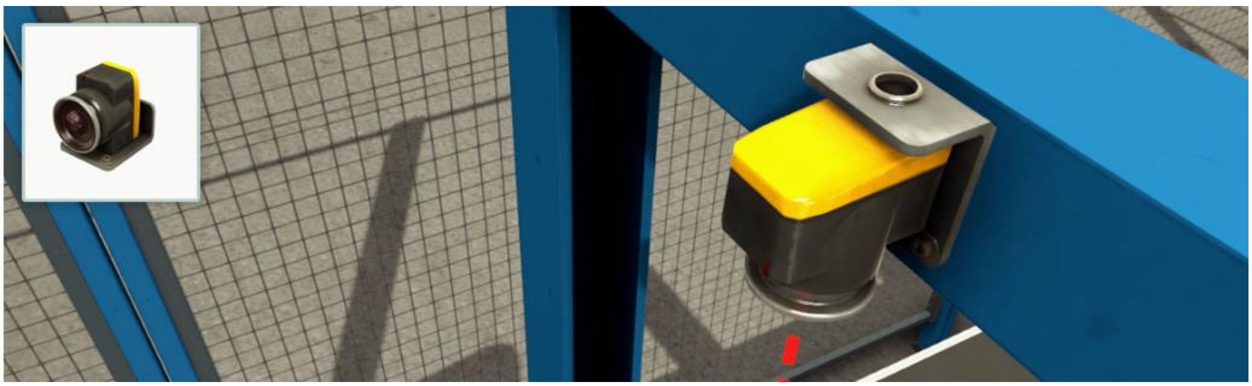

Figure 7 - Vision sensor [9]

2.4 Sorting and Routing.

The complex coordination of sorting and routing processes is what makes warehouses work so well and makes sure that goods can move through the facility without any problems. There is a direct link between this part of running a warehouse and how quickly, accurately, and efficiently the whole logistics chain works. Pivot arm sorters, which are the pinnacle of modern engineering and automation technology, are at the heart of these high-tech sorting and routing systems. These systems are an amazing mix of smart software and precise mechanics. They can move things around much faster and more accurately than traditional methods done by hand. Because they are finely tuned to respond to sensory inputs and work with a complex set of algorithms, pivot arm sorters are very good at doing a wide range of warehouse tasks. Modern sensing technologies have made pivot arm sorters much more useful by adding them to their systems. These sensors, which might have high-tech vision systems and cutting-edge recognition software, give real-time information about different aspects of a product. The sorters use this information to make smart choices, quickly putting things into groups based on things like size, shape, and color. With this level of accuracy, goods are not only sorted correctly, but they are also sent to their next destination in the warehouse in the fastest way possible.

Not only that, but pivot arm sorters work even better when combined with other automated systems, like roller conveyors. This integration makes it easy for goods to move from the sorting step to the transporting and storing steps, which speeds up the whole warehouse operation. Combining pivot arm sorters and conveyors is an example of an all-around approach to automating a warehouse, in which various systems work together to improve storage and logistics.

The fact that these sorting systems can be changed is another thing that stands out. They can be programmed to respond to different operational situations, which makes it easy for warehouses to handle high demand, unique product categories, and sudden changes in inventory levels. This adaptability is very important in today's fast-paced market, where customer needs and the way the supply chain works can change very quickly. Using such advanced sorting and routing systems also makes it much less likely that mistakes will happen during operations. By keeping people out of these processes as much as possible, warehouses can greatly lower the chance of mistakes, which improves reliability and customer satisfaction.

And here you can see the pivot arm sorter that used in this thesis (figure 8-9). It has a 45º power face arm diverter that is powered by a gearmotor. Equipped with a belt that helps to deviate the conveyed items onto the next part. The arm can rotate left or right according to the selected configuration.

- Belt speed: 2 m/s
- Arm angular speed: 5 rad/s

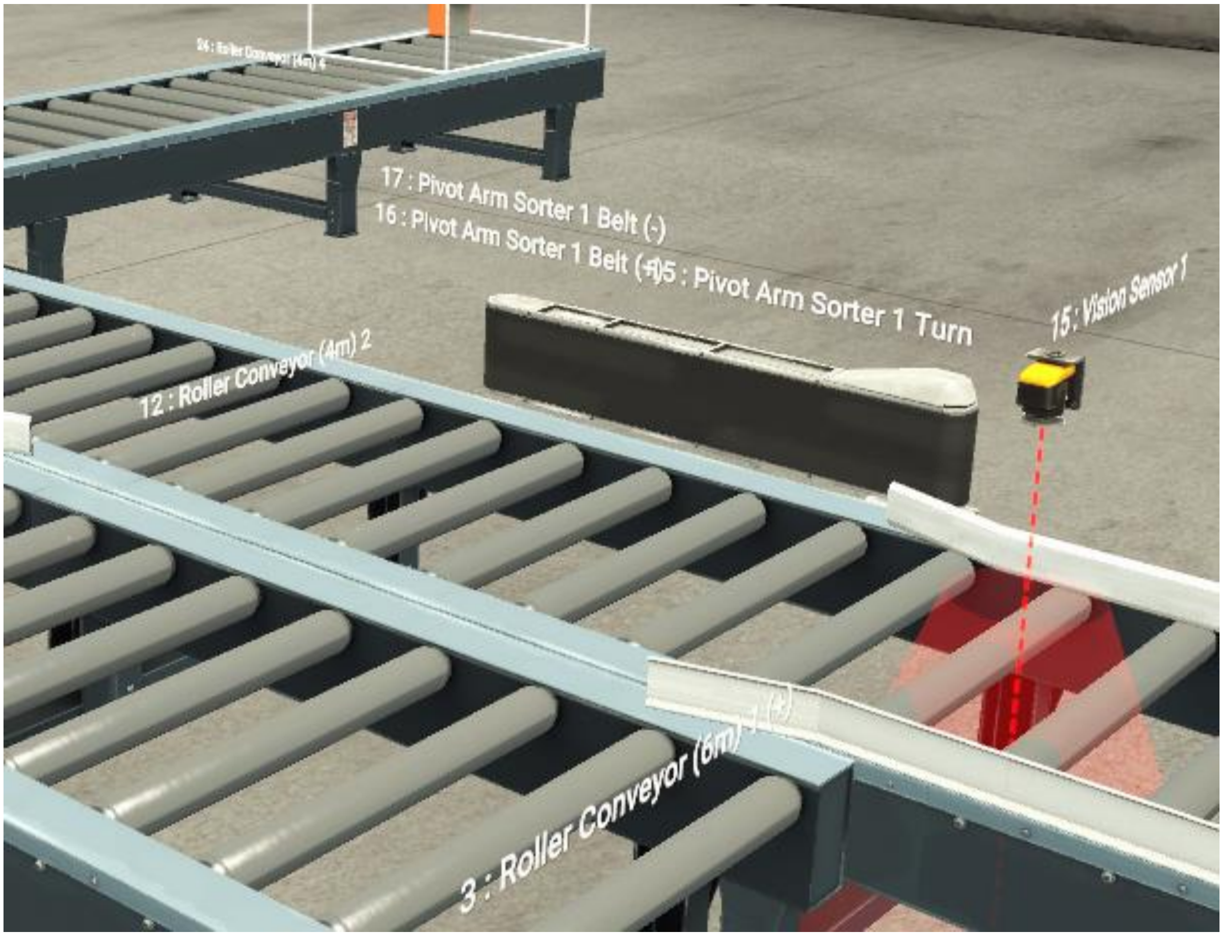

Figure 8 - Not diverted pivot arm sorter

Figure 9 - Diverted pivot arm sorter

Last but not least, pivot arm sorters and other cutting-edge sorting and routing technologies are more than simply an element of today's warehouses; they are a game-changer. Warehouse operations are now more streamlined and precise than ever before, thanks to these innovations in engineering and intelligent software.

2.5. Inventory Management.

When it comes to modern automated warehouses, smart inventory management is one of the most important things for running them smoothly. There have been big changes in this part of warehouse operations, especially in how they count their stock, which is required by law and accounting rules that vary from country to country. In the past, warehouses would do a full inventory count once a year, usually around the end of the company's fiscal year. Usually, this process meant that the warehouse had to temporarily stop all operations, including stopping all incoming and outgoing movements. There were, however, some big problems with this method. For example, it was hard to match up differences that could have happened at any time during the year, even up to 11 months ago. In the past few years, there has been a shift toward more flexible and ongoing ways of managing inventory. As an alternative to the traditional once-a-year stock count, cycle counting, also known as perpetual inventory counts, is becoming more popular. There are a number of benefits that this method offers in comparison to the conventional approach, which is that it involves conducting smaller-scale counts on a regular basis throughout the year. For example, cycle counting lets you keep track of things and keeps operations running smoothly because the warehouse does not have to be shut down for a full count. It makes sense for cycle counting to be used with the advanced automated systems that are common in modern warehouses. These systems allow for constant monitoring and tracking of inventory levels, giving real-time information about what items are in stock and where they are located in the warehouse. This level of detail about inventory makes sure that orders are filled more accurately and on time, which improves the overall efficiency of the warehouse.

In addition, automated warehouses use advanced inventory management techniques such as cycle counting, automated replenishment systems, and accurate inventory management. These strategies are very important for keeping a steady flow of goods going, avoiding stock-outs, and making the logistics process run more smoothly. But because of these improvements, auditors have sometimes seen that cycle counting methods work. Such systems can meet auditing needs as long as each stock line is counted and checked at least once a year. So, if the cycle counts are thought to be correct, it is possible to reliably get year-end stock numbers from the Warehouse Management System (WMS).

While this thesis does touch on inventory management, its primary focus is on other critical components of automated warehouse systems. Among these, the incorporation of robotics, the use of advanced sensing technologies, and the implementation of complex sorting systems all contribute to the modernization and efficiency of warehouse ecosystems. [13]

2.6. Retrieval and Storage.

The core of operational efficiency in automated warehouses is the complex and coordinated processes of retrieval and storage. The sophisticated systems of stacker cranes and conveyor networks, each of which plays a critical role in the moving of goods in a harmonious manner, are at the heart of this symphony of efficiency. There is no better example of precision and agility than stacker cranes when it comes to the realm of automated warehousing. In order to reduce the amount of time spent traveling between pickup and delivery points, these cranes move horizontally and vertically with ease, allowing them to navigate the aisles with a grace that belies their robust functionality. The operation of these systems is not merely a matter of simple transit; rather, it is an advanced dual-command system or an approach that interleaves individual tasks. This indicates that a stacker crane is able to simultaneously prepare to collect another pallet while simultaneously depositing a full pallet at the front of the aisle. The technological advancement in warehouse automation is exemplified by this sophisticated maneuver, which not only increases productivity but also exemplifies the advancement.

When they are working, the cranes, which are usually fixed to a certain aisle, are very efficient. However, these cranes are flexible because they can move across different aisles using transfer cars when storage needs are high but throughput needs are low. This adaptability is very important for getting the most out of space and meeting different storage needs. To make the system even more useful, the racks can be set up one or two pallets deep, which means that retractable forks on the cranes are needed to get to deeper storage. Fully automated systems use Automated Guided Vehicles (AGVs) to move things around. These AGVs pick up pallets and move them to the area where they will be sent out, closing the loop in the automated process of storing and retrieving items.

In addition to these stacker cranes, the warehouse has a large network of conveyor belts that make it easy for goods to move around. Working together with the cranes, the conveyor systems make sure that things move quickly and correctly through the warehouse. This synchronized operation not only makes the best use of storage space, but it also cuts retrieval times by a large amount.

To sum up, the advanced retrieval and storage systems in automated warehouses, which are made up of AGVs, stacker cranes, and conveyor networks that work well together, raise the bar for efficiency and productivity. Combining these cutting-edge technologies and making sure they work together is a key part of making an automated warehouse where accuracy, speed, and flexibility are very important.

CHAPTER 3: Software Components of Warehouse Automation In this thesis.

In the world of contemporary warehouse automation, the integration of specialized software tools is crucial for the implementation of a complex and smooth system. The purpose of this thesis is to investigate the important role that such integration plays in the process of orchestrating, testing, and refining operations within an automated warehouse environment.

There are three key software components that are the focus of attention: TIA Portal V17, Factory IO, and PLCSIM. Each of these components plays an important role in elevating the digital infrastructure surrounding the warehouse.

3.1 TIA Portal V17 in Warehouse Automation

Within the field of warehouse automation, TIA Portal V17 stands out as a key element, helping to perfectly coordinate and improve the performance of important hardware parts. It is more than just software; it is the framework that makes programming programmable logic controllers (PLCs) easy. This, in turn, makes it easier to control and manage many automated systems. It is like the digital Mozart of warehouse operations. The TIA Portal V17 has a huge collection of tools that were made to handle the complicated needs of automation. This software makes sure that all the important parts, like stacker cranes, conveyor belts, and advanced sorting systems, work together smoothly in the warehouse by carefully coordinating their complex dance. One of the best things about TIA Portal V17 is that it can manage and sync a lot of different automation parts. The complex features of the system allow for smooth communication and precise control throughout the digital landscape of the warehouse. This level of integration is necessary to make sure that all the hardware works together and with the overall automation plan.

For automating warehouses, TIA Portal V17 is more than just a software solution. It acts as the hub, giving the necessary precision and control to make warehouse operations run smoothly and effectively. Putting in place an automated warehouse shows a dedication to technological excellence and makes sure that every part of it is done with accuracy, speed, and flexibility.

3.2 Factory IO: Simulation for Warehouse Testing

Factory IO is a cutting-edge 3D platform for simulating factories. It is at the cutting edge of warehouse automation. There is more to this software than meets the eye. It opens a door to a virtual world that very accurately replicates the complexities of industrial settings. A virtual factory can be built quickly thanks to its easy-to-use layout, which includes many industrial parts that are common in real-life settings. Factory IO offers a realistic experience through scenarios that range from the most basic to the most complex. It takes into consideration a significant number of applications in the industrial sector. Furthermore, in addition to its function as a platform for simulation, Factory IO is an extremely valuable educational resource, particularly designed for the purpose of providing comprehensive training on programmable logic controllers (PLC). It is not limited to programmable logic controllers (PLCs), but rather encompasses a wide range of technologies, such as microcontrollers, SoftPLC, Modbus, and many others. Because of its adaptability, Factory IO is a versatile tool that helps bridge the gap between theoretical knowledge and practical application in the field of industrial automation. Factory IO is an essential instrument that plays a crucial role in the meticulous examination and simulation of a wide variety of operational scenarios, workflows, and processes that are uniquely associated with warehouse environments. Through the use of its simulation capabilities, it is possible to proactively identify potential challenges, which in turn enables the refinement of processes and the optimization of system efficiency. When it comes to the development of automated systems, this proactive approach to troubleshooting and optimization is of great value. The ability to visually validate and refine PLC programming is a strong suit of Factory IO. The software provides an interactive and clear interface for testing and validating automation strategies by expertly depicting the interactions of hardware components within a simulated warehouse setting. When it comes to making sure that the theoretical designs become efficient, practical warehouse operations, this feature is invaluable.

In my thesis, I utilized the pre-existing "Automated Warehouse" template scene (figure 10) from the Factory IO application as a foundational element. This scene was then extensively modified and expanded upon to further develop and enhance various warehouse applications for the scope of my research (figure 11).

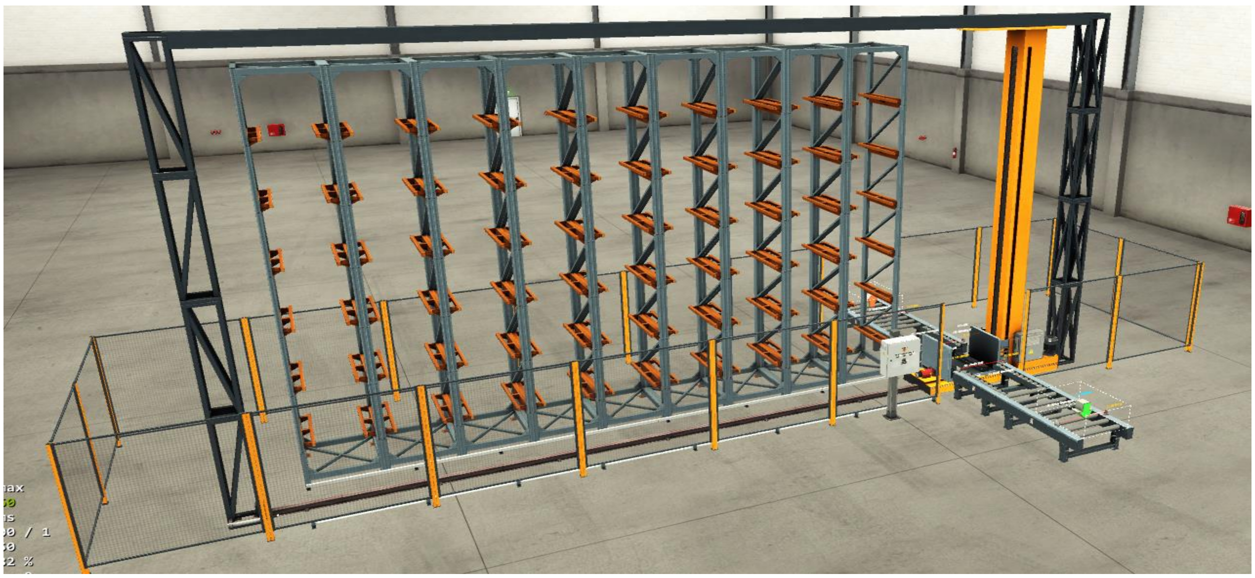

Figure 10 – Template scene that is given in the Factory IO [9]

Figure 11 – Expanded Factory IO scene

In the end, Factory IO becomes an important part of the progress in automating warehouses because it provides a complete and accurate simulation environment. Its job of providing a detailed and interactive platform for developing, testing, and validating automated warehouse setups is very important. This makes it possible for warehouse automation solutions to work well and be optimized.

3.4 PLCSIM: Validation and Testing

PLCSIM is an important tool for automating warehouses. It is made to make sure that Programmable Logic Controller (PLC) programs made in TIA Portal V17 are fully validated and tested. This simulation software is an important part of making a virtual environment that works like a real one where PLCs are used. This is an important step that needs to be taken to make sure that these systems work well, accurately, and easily with other systems in real warehouse automation situations. When people use this software, they get a platform that is both complete and complete, which lets them simulate and carefully look into how PLC programs work. By using this simulation, possible operational inefficiencies can be found and fixed before they become a problem during the development phase. Because of this preventative approach, there is a much lower chance that something will go wrong when these systems are put to use in a warehouse.

It is the Siemens S7-1200 PLC that is used as the automation control system in this thesis. This particular PLC is a small but powerful controller that can be used for a wide range of automation tasks in industrial settings, such as the described automated warehouse. The S7-1200 series is famous for its fast processing, built-in technology features, and ability to connect to a wide range of input and output modules. TIA Portal, its engineering framework, makes it easier to build automation projects by giving users an easy-to-use interface for setting up hardware and writing code. In an automated warehouse, this integration is very important for keeping track of how the stacker crane and the shelving system are working. PLCSIM works with TIA Portal V17 and Factory IO to create an ecosystem where testing and validation can happen at the same time. Making a direct link between the simulated warehouse model and the facility's PLC programming environment is a key part of this integration process as it makes sures that all the tests are complete. Having such a full testing area is important so that the PLC programs can be carefully looked over, made better, and shown to work.

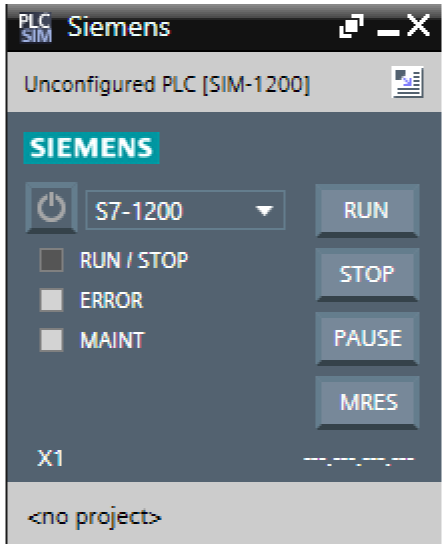

Figure 12 - PLCSIM S7-1200

In the most basic sense, PLCSIM is one of the most important parts of developing warehouse automation systems. It provides a strong and advanced platform that lets PLC operations be tested and confirmed before they are put into use. The role it plays in the project is not just helpful; it is very important for making sure that the live automation system works as accurately and efficiently as possible once it is up and running.

3.5. Integration and Communication

In the complicated world of warehouse automation, software components must be able to work together and talk to each other easily in order for the system to work well. To run a productive and efficient warehouse, you need to understand how these connections work and how they affect each other. TIA Portal becomes the main control center, expertly managing the flow of programming logic, commands, and data to keep the warehouse automation system running smoothly. It makes it easy for Factory IO and PLCSIM to talk to each other, so data can be sent and received in real time, and actions in Factory IO exactly match the logic programmed in the TIA Portal. Without the need for time-consuming and expensive physical testing, engineers can now validate and test automation processes in a virtual environment thanks to this robust integration. An essential component in creating a virtual warehouse is Factory IO, a 3D simulation platform. It carefully simulates how different hardware parts work by getting instructions and data from the TIA Portal and acting out those instructions in the digital warehouse representation. Before putting the automation system to use in the real world, engineers can use this complex communication loop to find possible bottlenecks or inefficient operations. [18] PLCSIM adds to this integration by giving a simulated environment designed for PLC programming. This gives a controlled environment to test and confirm PLC programs. It works perfectly with the TIA Portal, so the simulated environment is an exact copy of the real-world PLC hardware. This lets engineers fix bugs and improve PLC logic without affecting the real system. This unified method eliminates the chance of making mistakes or inefficient decisions during the PLC programming phase, guaranteeing the best performance of the automation system. [17] A lot of real-life case studies show how TIA Portal, Factory IO, and PLCSIM can change things when they work together seamlessly. Warehouse operators have been able to improve operational efficiency, cut down on mistakes, and speed up processes by using these tools. Integrated solutions make warehouse automation more reliable and effective by making the best use of resources and reducing downtime. [10]

3.6. Challenges and Considerations

Adding software to warehouse automation can be hard, so it needs to be carefully thought out and planned out so that everything runs smoothly. Pay close attention to how well software parts like TIA Portal, Factory IO, and PLCSIM work together. When different versions, updates, or protocols are used, they can often make it hard for systems that are connected to work well. It can be hard to get real-time data from software components to the warehouse environment to work together, especially when managing huge amounts of data all the time. Making sure that different software platforms, protocols, and systems can talk to each other and work with each other without any problems is essential for keeping operations running smoothly. To get around these problems, it is important to test all of the software's integrated parts very carefully. This method helps find problems with compatibility and makes sure that everything is in sync. Following standard communication protocols and guidelines makes it easier for devices to work together and lets data flow more smoothly.

Incorporating case studies or real-life examples of how these problems were solved in actual warehouse automation projects can also be useful. It can be easier to integrate things if you stress the importance of vendor support or working together to solve problems. This can be done by focusing on partnerships or dedicated support teams. It might also be helpful to talk about what the future holds for software integration for warehouse automation, like how AI or IoT will be used. This way of thinking ahead makes sure that warehouses are ready for new developments, which helps them stay ahead in the world of automation technology, which is always changing.

To avoid problems caused by different versions, software components must be regularly updated and maintained. Comprehensive training programs for warehouse staff make sure that integrated software systems are used effectively and that problems are resolved quickly. Monitoring software all the time lets you find and fix any problems with it before they happen.

Creating software integrations with scalability in mind makes it easier to add on to or change things as the needs of the warehouse change. Through integrated software systems, warehouses can improve operational efficiency by proactively addressing these problems and putting in place strategic measures.

CHAPTER 4 Control Logic and Program Architecture in Warehouse Automation

The warehouse automation system's control logic is like the building blocks that hold all of its different parts together and make sure they work together and make important decisions. The main job of this control logic is to make sure that all the functions of the automated warehouse ecosystem work together smoothly. At the heart of this framework is the complex orchestration of many parts working together. Every part, from the conveyors to the robotic arms and sensors, works like a part of the bigger machine. In order to run warehouse operations more efficiently, the control logic carefully coordinates their actions so that they work together without any problems. This control logic includes strong decision-making systems that are finely tuned to respond to changing cues in the environment. The system responds based on real-time sensor data and algorithms that have already been programmed. These algorithms figure out how to move around the warehouse and make split-second decisions to make sure that tasks are assigned and movements are planned in the best way possible.

In addition, the control logic makes it possible for parts to talk to each other, which creates a cohesive synergy. This makes it possible to quickly share information and adapt to different operational situations. It makes sure that actions taken by one part have an effect on other parts of the system and affect the steps that come after them to keep things running smoothly.

The control logic is like the brain of the warehouse automation system; it has to be smart and flexible in order for everything to work together smoothly.

4.1 Introduction to the Main [OB1] Block in TIA Portal

The Main [OB1] block houses the system's intelligence and control and is the main command hub in the TIA Portal programming environment. Its many functions are very important for managing and coordinating the complicated dance of machines and processes in warehouse automation. This project is used for a number of important functions, including:

Initialization is a basic task that involves carefully setting up communication channels, configuring hardware devices, and loading important program blocks. It turns on the system's parts and makes sure they are primed and ready to work.

Start-Stop Sequence: The Main [OB1] block carefully controls the beginning and ending sequences as the system's gatekeeper. It carefully checks that safety conditions are met, turns parts on and off, and plans the smooth start or end of operations.

Error Handling: This block is like a watchful parent; it finds and fixes mistakes that happen in the automation system. It quickly finds the source of problems, fixes them, and lets operators know about any problems right away, so there is as little downtime as possible.

Synchronization: Synchronization is the key to a harmonious symphony. The Main [OB1] block makes sure that all the different parts work at the same time and perfectly with each other. It carefully coordinates actions, sequences, and data flow so that the whole thing works together smoothly.

Reporting: "Operating as the recorder of system activities" does not change the subject of this block. This block makes detailed reports about the system's status, performance metrics, and error logs. These reports give important information for analyzing and improving systems.

1. Start-Stop Sequence: Main [OB1]. The main purpose of the start-stop sequence is to serve as the conductor, starting and stopping the whole operational performance and clearly controlling when Factory IO starts in the system. This part is very important, like a great conductor setting the pace for the warehouse automation symphony. At its core, this sequence is the guardian that makes sure Factory IO smoothly moves from a state of dormancy to a state of busy activity. As you press a button, there is a complex set of rules that must be followed to make sure that safety measures, operational requirements, and the exact moment to bring the simulation to life are all met. Imagine this sequence as the guardian, meticulously ensuring that every safety parameter and functional prerequisite is diligently observed as Factory IO springs into action. It encapsulates an intricate algorithm, a choreographed dance that delicately holds the key to initiating the harmonious rhythm of the factory simulation.

This sequence is more than just a "start" command; it is like the conductor's baton, coordinating many parts to wake up Factory IO exactly when the stage is set. It takes on the responsibility of bringing the simulation to life, making sure that it starts perfectly and ends just as perfectly when it reaches its peak performance. The system's ability to deal with dynamic data is demonstrated by the inclusion of the MOVE command in this network. The control system receives operational flags or data points from it, and the operational state of the warehouse environment is changed. The proper execution of logical operations and the assurance of an appropriate response to user input and system conditions are both controlled by this command.

Basically, this start-stop sequence is the overture that sets the stage for Factory IO to work well in the warehouse simulation as can be seen in the figure 13. Its precise timing, protection of safety measures, and orchestration of the start and end of the simulation show how important it is to the orchestra of warehouse automation.

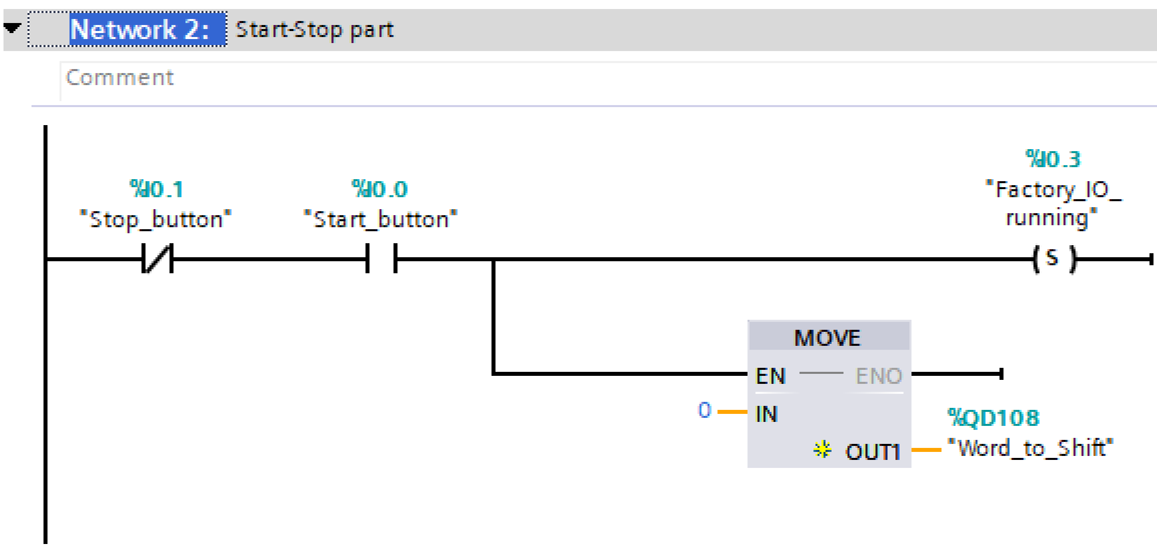

Figure 13 - Start-stop sequence.

2. Pivot Arm Code: Moving and keeping track of pallets in the warehouse is the job of this code. It makes sure that the pallets are sorted correctly and quickly gets them to where they need to go. The screenshot below shows that the TOF (Timer On Delay) function is an important part of the warehouse automation system that was made for this project. This particular use of the TOF function in the TIA Portal programming environment made it easier to precisely control timed actions that were important to the operation sequences of the automation system. As you can see from the screenshot, the TOF function is being used strategically. Its configuration and role in

controlling pivotal actions, especially the duration of the vision sensor-controlled pivot arm's activation, are clearly shown. This part of the article will go into detail about how to use the TOF timer function to set up timed actions in the automation program. Specifically, I will talk about how it can be used to control how long the pivot arm moves after receiving input from the vision sensor. Thus, the TOF timer block keeps the pivot arm sorter turned on for a configurable amount of time whenever the vision sensor signals it as shown in the figure 14.

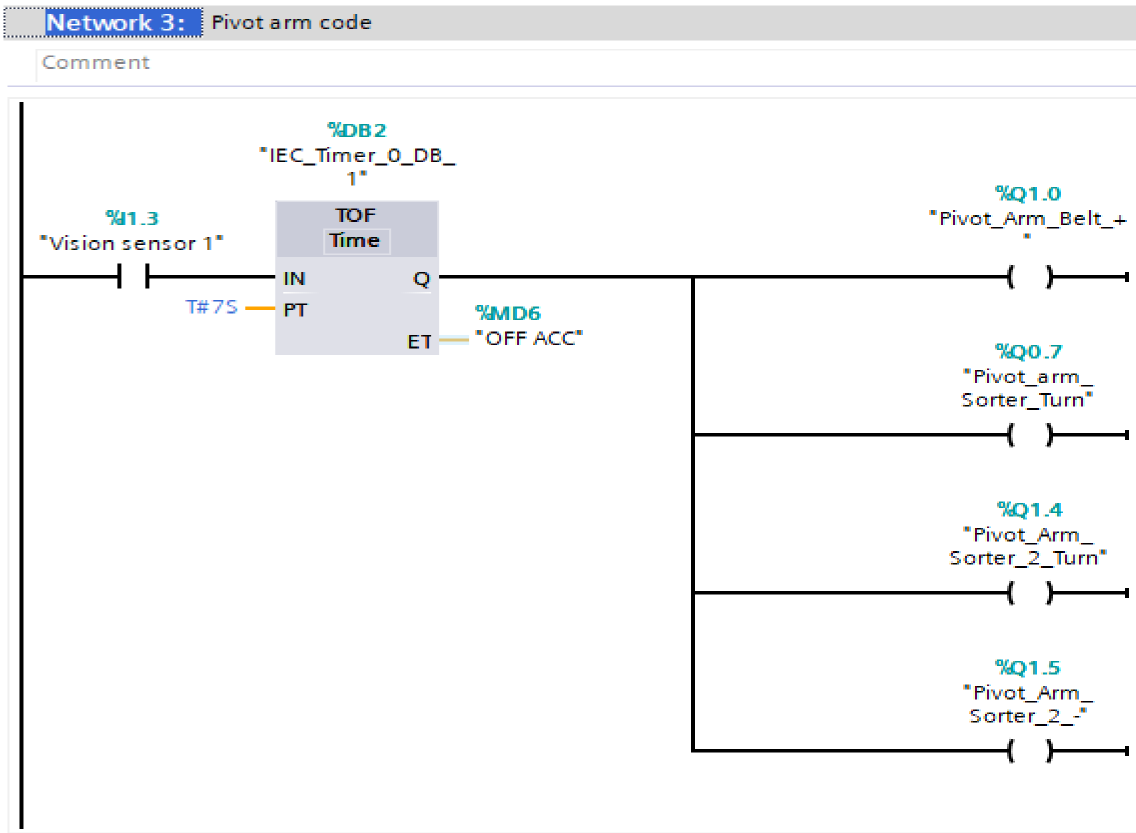

Figure 14 - Pivot arm code

3. Waiting for Loading Conveyor: The "Waiting for Loading Conveyor" section functions as a careful conductor, arranging a flawless symphony within the complex ballet of a warehouse's automated procedures. The code for the pivot arm is displayed in the figure, along with the timer for the overall order of magnitude. Together, the stacker crane and the conveyor are able to keep their movements in perfect sync with one another. Imagine for a moment that the stacker crane is exerting a great deal of effort in order to maintain its predetermined routine of putting pallets inside the rack. The "Waiting for Loading Conveyor" segment acts as the silent sentinel in the midst of

this complicated operation. Its purpose is to make certain that the movements of the crane and the readiness of the conveyor are in perfect harmony with one another. The objective of this break is not simply to provide a pause; rather, it is to meticulously time a break in order to choreograph a smooth transition between these two essential entities. This break will be conducted in order to achieve this goal. A strategic pause that is purposefully incorporated into the operation of the loading conveyor is referred to as an interlude, and it is presented in this section. This intermission has been purposefully designed with the intention of waiting until the stacker crane has completed its balletic routine and returned to its starting position.

This intermission has been purposefully designed with the intention of waiting until the stacker crane has completed its balletic routine and returned to its starting position. This is the intention behind the design of this intermission. This selective pause, which enables exquisite synchronization, makes it possible to take a brief pause that is meticulously timed to ensure that the conveyor stays at rest until the crane is ready for the next performance phase. The fact that it allows for exquisite synchronization makes this pause possible. It is possible for this segment to carry out a function that goes beyond simple timing because it contains a sophisticated logic that has been painstakingly crafted to ensure that the loading conveyor comes to life when the crane is ready to perform its subsequent action. This segment is able to perform this function because it encapsulates the logic. Because of the intricate choreography that is being performed, the warehouse's busy operation is able to maintain a fluid continuity. Due to this, there is no longer any possibility that the pivotal placements of the crane and the role that the conveyor plays in the flow of material will come into contact with one another or cause interruptions. This is because there is no longer any chance that this will occur, come into contact with one another or cause interruptions.

Additionally, this carefully orchestrated synchronization results in a plethora of operational efficiencies throughout the organization. A reduction in the likelihood of conflicts or overlaps can be achieved by coordinating the movements of these essential components. This provides protection against any disruptions that could potentially slow down the workflow. This meticulous orchestration ensures a smooth handoff, which in turn maximizes the overall efficiency of the warehouse automation system and optimizes the utilization of available resources.

The essence of this segment is that it exemplifies the precision and foresight that is necessary to guarantee that every component plays its part in perfect harmony with the intricate choreography of the warehouse. It is the strategic pause that serves as the linchpin, fostering an unbroken rhythm in the operational cycle. This ensures that every movement contributes in a seamless manner to the overall symphony of efficient warehouse automation.

4.2 Inputs and outputs.

This chapter goes into detail about how to make sure that the inputs and outputs of Factory IO and the TIA Portal work together smoothly in an automated warehouse. Factory IO offers a visual and interactive simulation platform that acts like the actions that are programmed into a PLC.

Figure 15 - PLC module in Factory IO

You can also see the outputs and inputs connected to each port here in the figure 15.

The PLC tags in TIA Portal are what make this interaction possible. They are the control language that turns operational commands into tasks that can be done. They do many things, such as starting the stacker crane's movement, controlling the conveyor systems, and checking the states of the equipment.

PLC tags

	Name	Tag table	Data type	Address	Retain	Acces...	Writa...	Visibl...	Comment
1	Stop_button	Standard-Variab...	Bool	%I0.1	☐	☑	☑	☑	
2	Start_button	Standard-Variablen...	Bool	%I0.0	☐	☑	☑	☑	
3	Roller_conveyor (6m)	Standard-Variablen...	Bool	%Q0.0	☐	☑	☑	☑	
4	Loading_conveyor	Standard-Variablen...	Bool	%Q0.1	☐	☑	☑	☑	
5	Capacitive_sensor_1	Standard-Variablen...	Bool	%I0.2	☐	☑	☑	☑	
6	Factory_IO_running	Standard-Variablen...	Bool	%I0.3	☐	☑	☑	☑	
7	Stacker_crane_Moving-x	Standard-Variablen...	Bool	%I0.4	☐	☑	☑	☑	
8	Stacker_crane_Moving-z	Standard-Variablen...	Bool	%I0.5	☐	☑	☑	☑	
9	Stacker_crane_Left-limit	Standard-Variablen...	Bool	%I0.6	☐	☑	☑	☑	
10	Stacker_crane_Right-Limit	Standard-Variablen...	Bool	%I0.7	☐	☑	☑	☑	
11	Stacker_crane_Middle-Limit	Standard-Variablen...	Bool	%I1.0	☐	☑	☑	☑	
12	Stacker_Crane_Lift	Standard-Variablen...	Bool	%Q0.2	☐	☑	☑	☑	
13	Stacker_Crane_Left	Standard-Variablen...	Bool	%Q0.3	☐	☑	☑	☑	
14	Stacker_Crane_Right	Standard-Variablen...	Bool	%Q0.4	☐	☑	☑	☑	
15	Word_to_Shift	Standard-Variablen...	DInt	%QD108	☐	☑	☑	☑	
16	Destination	Standard-Variablen...	DInt	%QD112	☐	☑	☑	☑	
17	Timer_1_Start	Standard-Variablen...	Bool	%M1.5	☐	☑	☑	☑	
18	Timer_1_PT	Standard-Variablen...	Time	%MD10	☐	☑	☑	☑	
19	Timer_1_done	Standard-Variablen...	Bool	%M1.6	☐	☑	☑	☑	
20	Timer_1_Val	Standard-Variablen...	Time	%MD14	☐	☑	☑	☑	
21	Loading_Conveyor_1_wait	Standard-Variablen...	Bool	%M1.7	☐	☑	☑	☑	
22	stacker_crane_target_position	Standard-Variablen...	DInt	%QD32	☐	☑	☑	☑	
23	capacitive_sensor_2	Standard-Variablen...	Bool	%I1.1	☐	☑	☑	☑	
24	waiting_for_crane_return	Standard-Variablen...	Bool	%M1.1	☐	☑	☑	☑	
25	Vision sensor 1	Standard-Variablen...	Bool	%I1.3	☐	☑	☑	☑	
26	Pivot_arm_Sorter_Turn	Standard-Variablen...	Bool	%Q0.7	☐	☑	☑	☑	
27	Pivot_Arm_Belt_+	Standard-Variablen...	Bool	%Q1.0	☐	☑	☑	☑	
28	Roller_Conveyor_3	Standard-Variablen...	Bool	%Q1.1	☐	☑	☑	☑	
29	Roller_Conveyor_2	Standard-Variablen...	Bool	%Q1.2	☐	☑	☑	☑	
30	Roller_Conveyor_1	Standard-Variablen...	Bool	%Q1.3	☐	☑	☑	☑	
31	OFF ACC	Standard-Variablen...	Time	%MD6	☐	☑	☑	☑	
32	Pivot_Arm_Sorter_2_Turn	Standard-Variablen...	Bool	%Q1.4	☐	☑	☑	☑	
33	Pivot_Arm_Sorter_2_-	Standard-Variablen...	Bool	%Q1.5	☐	☑	☑	☑	
34	<Add new>				☐	☑	☑	☑	

Figure 16 - PLC tags

This figure 16 shows the PLC tags and how the logical programming elements are linked to their actions in the Factory IO simulation. Additionally, it demonstrates how the automated processes rely on the exchange of data in real-time.

Ultimately, for automated warehouse operations to run smoothly, it is essential that Factory IO's simulations communicate with the PLC tags in the TIA Portal. This results in an enhanced digital twin experience, which streamlines operations and simplifies testing.

4.3 Stacker Crane Code:

The Stacker Crane Block 1 (FC) is as follows: This functional block is devoted to the specific operations that are performed by the stacker crane. These operations include movement coordination, pallet handling, and precise placement within the racks. The complex maneuvers of the stacker crane are meticulously governed within the code of the Structured Control Language (SCL) in order to maximize its functionality within the warehouse automation system. The code has been meticulously divided into separate regions, each of which is accountable for the coordination of particular stages of the crane's operational sequence.

REGION Ready: This section is the precursor to the crane's working cycle. In response to particular sensor inputs, it prepares the system to begin the process of picking up pallets with the pallets. The activation of predefined sensor conditions results in the establishment of critical parameters, and a timer is then set to initiate the subsequent actions.

REGION Timer 1: This segment, which is an essential component of the code, is responsible for managing the timing and duration of the essential activities that are carried out by the stacker crane. It is responsible for coordinating the temporal sequence of movements and transitions, which guarantees the precise execution and synchronization of the crane's various tasks. (Figure 17)

```
REGION Timer 1
    // Timer 1 Setup
    "IEC_Timer_1_DB".TON(IN:="Timer_1_Start",
                         PT:="Timer_1_PT",
                         Q=>"Timer_1_done",
                         ET=>"Timer_1_Val");
END_REGION
```

Figure 17 - Timer code

REGION Step 1 to Step 9:

This is the precise symphony of the stacker crane.

Within the core of the automated warehouse, the Stacker Crane executes a dance that has been meticulously choreographed and is broken down into nine distinct steps. A specific action is represented by each step, which demonstrates the crane's remarkable agility and precision in the midst of the hectic environment of the warehouse.

What Is Most Important About Each Step:

1. Beginning with a Forks to the left: The crane's performance starts off with a graceful extension of its forks to the left, which establishes the stage for the entire sequence.

2. Raising the Pallet: In the second step, the crane elegantly lifts the pallet, lifting it to the required height with a fluid vertical movement.

3. Returning to Center: After the lift, the crane gently brings its forks back to the central position, ready for the next part of the performance.

4. Gliding to the Destination: The crane moves smoothly across the warehouse floor, directed to its designated destination. This lateral finesse ensures perfect positioning for what comes next.

5. Reaching Right: In this step, the crane extends its forks to the right, preparing for the precise placement of the pallet into the racks.

6. Lower forks: With finesse, the crane gently lowers the pallet, ensuring it snugly fits within the storage racks.

7. Back to Center Stage: After the successful placement, the crane brings its forks back to the central position, poised for the next task.

8. Returning to the Spotlight: The crane concludes its performance by gracefully returning to its central position, marking the end of this meticulously orchestrated sequence.

The complex movements of the crane are revealed in these nine stages, highlighting its essential function as the foundation of efficiency in the warehouse automation system. Every step of the Stacker Crane's balletic dance is orchestrated to ensure the warehouse runs smoothly, and the effect is hypnotic. And additionally, you can see the full SCL code in the addendum.

REGION Waiting FOR the stacker TO get back TO center: One of the most important aspects of the code is that this particular region makes it easier for the stacker crane and the loading conveyor to coordinate their movements. By intelligently pausing the loading conveyor only when the stacker crane is placed in the pallet, it ensures that a synchronized workflow is maintained. The conveyor is able to wait selectively thanks to this strategic pause, which allows the workflow to be optimized without any interruptions that are not necessary. Here in figure 18, you can see detailed SCL code.

```
REGION Waiting FOR stacker TO get back TO center
    //Waiting until stacker gets free
    IF "waiting_for_crane_return" = TRUE AND "capacitive_sensor_2" = TRUE THEN
        "Roller_conveyor (6m)" := FALSE;
    END_IF;
END_REGION
```

Figure 18 - Waiting for the stacker crane to get back to the center.

Word to shift.

The concept of "word shift" is going to be discussed in depth, along with the reasons why it is so important in the process of orchestrating the operational phases of our stacker crane system. Imagine that the sequential steps of the crane's movement process are represented by a data structure, which is our 32-bit integer double word, which is referred to as QD-108 in the code. This data structure is analogous to a word diagram that is 16 bits in thickness. When the code is being initiated, the value of QD-108, which is initially set to zero, is a reflection of where we are in the beginning of the operational sequence. In response to the detection of a pallet by reflective sensor 5, this value changes to 1, which represents the beginning of the first step in our operation, which is getting ready to lift and position a pallet within the rack. In the course of the crane's execution of each step, QD-108 goes through a transition that is methodical. As soon as the forks are extended, the value changes to 2, which indicates that the next step, which is lifting the pallet, has been completed. Consequently, subsequent steps are carried out in the same manner: step 3 corresponds to the value 4 in QD-108, which serves as a marker for the process milestones until all nine necessary steps for pallet placement and crane realignment have occurred. While this was going on, we had the opportunity to implement a straightforward incremental strategy for QD-108. Despite the fact that it is not a direct application of the shift command, the "word shift" method was selected. This method is analogous to the left shift operation. It is the selection of this approach that serves the purpose of accurately tracking the progress through the sequential steps, despite the fact that the technique involved is different.

Among the deliberations considered was the use of an explicit shift left command. However, assigning the required values directly to QD-108 proved to be a more streamlined approach. Notably, QD-108 retains its label as "word to shift," maintaining clarity in its function within the code.

A reset is triggered when the system reaches step 9, which is the point at which QD-108 receives a value of 256. This reset ensures that all parameters are reset to zero and prepares the system for a new operational cycle.

This structured approach, despite appearing to be complex, guarantees a methodical and effective execution of the stacker crane's tasks, which highlights the significance of organized programming in the process of orchestrating the complexities of warehouse automation. This can be seen by the fact that this structured approach guarantees a methodical and effective execution of the stacker crane's tasks.

A harmonious and efficient operation is achieved by the warehouse automation system through the implementation of such a structured and meticulous control logic in the SCL code. This allows the system to minimize downtime, optimize task execution, and ensure seamless synchronization among its integral components.

4.5. Program Block for Communication between Factory IO and TIA Portal. There is a pivotal bridge that facilitates communication and a symbiotic relationship between the simulation platform and the live environment. This bridge is the Program Block that is dedicated to enabling communication between Factory IO and TIA Portal. By acting as a conduit for the exchange of data and commands in a seamless manner, it helps to foster a cohesive integration that ensures synchronization between these two distinct yet interconnected realms. This specialized block serves as the linchpin in the process of achieving harmony between the virtual simulation that is managed through the TIA Portal and the operations that are managed in the real world when using Factory IO. Its design and functionality make it possible to communicate in both directions, which makes it possible for data to flow back and forth without any difficulty. This exchange includes various important pieces of information, such as readings from sensors, commands from actuators, the current status of processes, and other components of the system that are essential. In addition to the transmission of data, the significance of the block extends further. It performs the function of a translator, ensuring that the dynamics of the simulated environment and the practical applications found in the TIA Portal are compatible with one another and coherent with one another. The validation and fine-tuning of control algorithms, the verification of system responses, and the simulation of real-world scenarios—all of which take place within the virtual environment—require this synchronization to be completely accurate.

Furthermore, the Program Block's function in the process of data exchange is not restricted to a flow in only one direction; rather, it functions as a facilitator for a dynamic feedback loop. Information gathered from the live environment influences the simulation in Factory IO, allowing for real-time adjustments and simulations that mirror the actual operating conditions.

This particular Program Block serves as the foundation of the architecture, ensuring that the simulated and real-world environments are in perfect harmony with one another. It makes it possible to have a conversation that is seamless, ensuring that any changes that occur in one realm are accurately reflected and reciprocated in the other. This robust communication framework plays a significant role in validating designs, testing functionalities, and honing the efficiency of operations prior to their implementation in the live system. As a result, it ultimately contributes to improved reliability and performance in the industrial setup. You can see the whole screenshot of the code in the addendum.

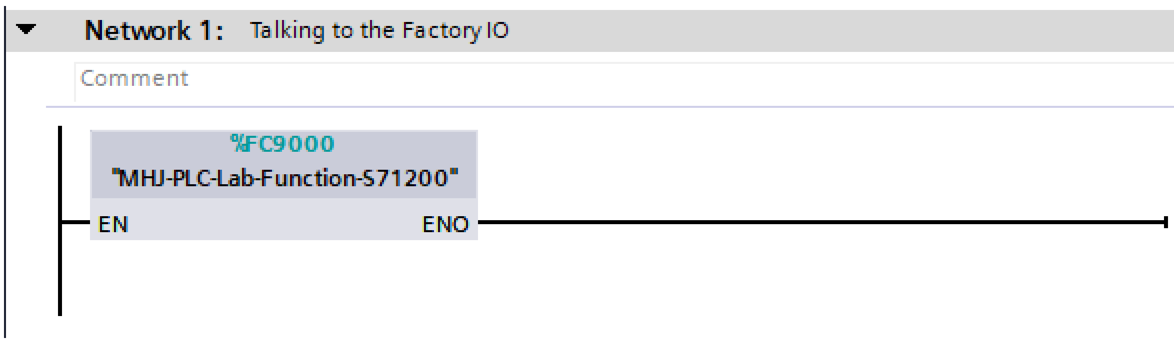

Figure 19 - Program Block for Communication between Factory IO and TIA Portal. [9]

CHAPTER 5: Conclusion

This thesis has provided an extensive analysis of the transition from traditional to fully automated warehouse systems, focusing on the integration of advanced software and control logic. The study delved deep into the functionalities of TIA Portal, Factory IO, and PLCSIM, uncovering their pivotal roles in achieving a seamless and efficient warehouse automation system.

Key Findings:

1. Contrast between Traditional and Automated Warehouses: A significant finding was the stark contrast in operational speed between traditional and fully automated warehouses. Automated warehouses, particularly those utilizing stacker cranes, demonstrated a substantial increase in efficiency, reducing the average time for pallet placement from approximately 1 minute [19] (in traditional settings) to 30 seconds.[20]

2. Software Integration: The thesis highlighted the importance of seamless integration of software components, ensuring the synchronicity and efficiency of warehouse operations.

3. Innovative Control Logic: The development of intricate control logic within the Main [OB1] block and the application of the TOF timer function were crucial in enhancing operational precision and synchronization.

Practical Implications and Recommendations:

- Adaptation to Different Warehouse Models: Emphasize the need for software architectures that are adaptable to varying warehouse sizes and operations.

- Sustainability in Automation: Advocate for the integration of energy-efficient and sustainable practices in warehouse automation to reduce environmental impact.

- Continuous Software Management: Stress the importance of ongoing updates and maintenance for software components to ensure long-term efficiency and compatibility

Future Research Directions:

- Exploration of Emerging Technologies: Future studies should examine the integration of AI and IoT within warehouse automation to enhance predictive analytics and operational efficiency.

- Environmental Impact Assessment: Additional research on the environmental implications of warehouse automation could provide valuable insights into sustainable practices in logistics.

- Synergy of Human and Automation: Investigate the collaborative potential between human workers and automated systems, focusing on maximizing efficiency and safety.

In conclusion, the exploration conducted in this thesis not only sheds light on the operational enhancements brought by warehouse automation but also sets the stage for future advancements in logistics and supply chain management. The marked increase in speed and efficiency in automated warehouses, as compared to traditional ones, underscores the transformative potential of automation, heralding a new era of productivity and effectiveness in warehouse operations.

Beyond the obvious benefits to efficiency, using automation technologies has big positive effects on the environment. Aside from making things more efficient, using automation technologies is also very good for the environment. A more environmentally friendly supply chain uses resources more efficiently and throws away less, which is helped by automated systems. A lot of thought should go into making new automated warehouses more environmentally friendly. For example, using renewable energy and starting recycling programs are both good ideas. With the goal of finding solutions that strike a balance between making money and taking care of the environment, it is very important for the logistics industry to support sustainability as a core value.

References

[1] "Automation in Warehouse Development" Roelof Hamberg

[2] https://www.123rf.com/photo_90693568_classic-warehouse-with-pallet-3d-rendering-image.html

[3] https://cirrustech.com/cirrus-semi-automated-case-picking-systems/

[4] https://www.mecalux.com/blog/how-automated-warehouse-works

[5] Automated Storage and Retrieval System (AS/RS) - MHI pdf.

[6] Conveyors. Application, Selection, and integration second edition - Patrick M. McGuire.

[7] [Vision Systems in Warehouse Automation - Robotics Tomorrow](https://www.roboticstomorrow.com/article/2021/warehouse-automation-how-vision-systems-are-transforming-the-industry/17720).

[8] [Understanding Pivot Arm Sorters - Logistics Tech Outlook](https://www.logisticstechoutlook.com/news/pivot-arm-sorters-an-integral-technology-in-the-world-of-warehouse-automation-nid-1595.html)

[9] https://docs.factoryio.com/

[10] [Citation: Coughlin, J. (2023, January 24). Warehouse automation software: A guide to the best solutions. Retrieved October 4, 2023.]

[11] Warehouse & Distribution Science" by John Bartholdi III and Steven Hack

[12] Benefits of Automated Storage Racking for Warehouse Operations. Lean Manufacturing Blog. (n.d.). Retrieved December 9, 2023, from https://www.mecalux.com/blog/advantages-of-automated-storage-and-retrieval-systems

[13] Warehouse management by Gwynne Richards.

[17] [Citation: Coughlin, J. (2023, January 24). Warehouse automation software: A guide to the best solutions. Retrieved October 4, 2023.]

[18] [Citation: Despeigne, A. (2022, July 13). How to increase warehouse efficiency with Factory IO. Retrieved October 4, 2023.]

[19] Top 5 Reasons Warehouse Automation is Important for Your Business. HubSpot. (n.d.). Retrieved December 9, 2023, from https://knowledge.hubspot.com/get-started/automate-your-processes

[20] Benefits of Automated Storage Racking for Warehouse Operations. Lean Manufacturing Blog. (n.d.). Retrieved December 9, 2023, from https://www.mecalux.com/blog/advantages-of-automated-storage-and-retrieval-systems

For additional books to reference in your thesis that are not listed in your current references, consider the following:

[21] “Logistics and Supply Chain Management" by Martin Christopher.

[22] “Inventory Accuracy: People, Processes, & Technology" by David J. Piasecki.

[23] “Material Handling Equipment" by Niels J. Gornet.

[24] "Production and Operations Management" by S. Anil Kumar and N. Suresh

[25] “Supply Chain Logistics Management" by Donald J. Bowersox, David J. Closs, and M. Bixby Cooper

Addendum.

Program Block for Communication between Factory IO and TIA Portal.

```
#Value:=PEEK(area := 16#82,
        dbNumber := 0,
        byteOffset := 511);
#Value := #Value + 1;

POKE(area := 16#82,
        dbNumber := 0,
        byteOffset := 511,
        value := #Value);

POKE(area:=16#81,
        dbNumber:=0,
        byteOffset:=1016,
        value:=#Value_01_DW);
POKE(area := 16#81,
        dbNumber := 0,
        byteOffset := 1020,
        value := #Value_02_DW);

POKE(area := 16#81,
        dbNumber := 0,
        byteOffset := 511,
        value := B#16#00);

FOR #forVal := 0 TO 120 DO
    FOR #forVal_2:=0 TO 10 DO
        #rdTimeReturn:=RD_SYS_T(#outputTime);
        #rdTimeReturn := WR_SYS_T(#outputTime);
        #rdTimeReturn := RD_SYS_T(#outputTime);
        #rdTimeReturn := WR_SYS_T(#outputTime);
    END_FOR;
    #SyncVal:= PEEK(area := 16#81,
                    dbNumber := 0,
                    byteOffset := 511);
    IF #SyncVal = #CompVal THEN
       GOTO M_1;
    END_IF;
END_FOR;
RETURN;
```

```
M_1:
POKE(area := 16#81,
     dbNumber := 0,
     byteOffset := 511,
     value := B#16#0);
```

Stacker Crane Code:

```

#Value:=PEEK(area := 16#82,
        dbNumber := 0,
        byteOffset := 511);
#Value := #Value + 1;

POKE(area := 16#82,
        dbNumber := 0,
        byteOffset := 511,
        value := #Value);

POKE(area:=16#81,
        dbNumber:=0,
        byteOffset:=1016,
        value:=#Value_01_DW);
POKE(area := 16#81,
        dbNumber := 0,
        byteOffset := 1020,
        value := #Value_02_DW);

POKE(area := 16#81,
        dbNumber := 0,
        byteOffset := 511,
        value := B#16#00);

FOR #forVal := 0 TO 120 DO
    FOR #forVal_2:=0 TO 10 DO
        #rdTimeReturn:=RD_SYS_T(#outputTime);
        #rdTimeReturn := WR_SYS_T(#outputTime);
        #rdTimeReturn := RD_SYS_T(#outputTime);
        #rdTimeReturn := WR_SYS_T(#outputTime);
    END_FOR;
    #SyncVal:= PEEK(area := 16#81,
                    dbNumber := 0,
                    byteOffset := 511);
    IF #SyncVal = #CompVal THEN
       GOTO M_1;
    END_IF;
END_FOR;
RETURN;

```

```

M_1:
POKE(area := 16#81,
        dbNumber := 0,
        byteOffset := 511,
        value := B#16#0);



```

```
REGION Ready
    // Getting ready to pick up the pallet
    IF "Capacitive_sensor_1" = 1 AND "Stacker_crane_Middle-Limit" THEN
        "Word_to_Shift" := 1;
        "Timer_1_PT" := T#0.5s;
    END_IF;
END_REGION

REGION Timer 1
    // Timer 1 Setup
    "IEC_Timer_1_DB".TON(IN:="Timer_1_Start",
                         PT:="Timer_1_PT",
                         Q=>"Timer_1_done",
                         ET=>"Timer_1_Val");
END_REGION

REGION Step 1
    //  Left
    IF "Word_to_Shift" = 1 THEN
        "Stacker_Crane_Left" := TRUE;
        "Word_to_Shift" := 2;
    END_IF;
END_REGION

REGION Step 2
    // Lift
    IF "Stacker_crane_Left-limit" AND "Word_to_Shift" = 2 THEN
        "Stacker_Crane_Lift" := 1;
        "Timer_1_Start" := TRUE;
        "waiting_for_crane_return" := TRUE;
        "Word_to_Shift" := 4;
    END_IF;

END_REGION
```

```
REGION Step 3
    // to center
    IF "Word_to_Shift" =4 AND "Timer_1_done" THEN
        "Stacker_Crane_Left" := FALSE;
        "Timer_1_Start" := FALSE;
        "Word_to_Shift" := 8;
    END_IF;
END_REGION

REGION step 4
    // Move to Place in Rack
    IF "Stacker_crane_Middle-Limit" AND "Word_to_Shift" = 8 THEN
        "Destination" := "Destination" + 1;
        "stacker_crane_target_position" := "Destination";
        "Word_to_Shift" := 16;
        "Timer_1_Start" := TRUE;
    END_IF;

END_REGION

REGION Step 5
    // Move into Rack
    IF NOT "Stacker_crane_Moving-x" AND NOT "Stacker_crane_Moving-z" AND "Timer_1_done" AND "Word_to_Shift" = 16 THEN
        "Stacker_Crane_Right" := TRUE;
        "Timer_1_Start" := FALSE;
        "Word_to_Shift" := 32;
    END_IF;
END_REGION

```

```

REGION Step 6
    // Lower Forks
    IF "Stacker_crane_Right-Limit" AND "Word_to_Shift" = 32  THEN
        "Stacker_Crane_Lift" := FALSE;
        "Timer_1_Start" := TRUE;
        "Word_to_Shift" := 64;
        ;
    END_IF;
END_REGION

REGION Step 7
    // Back to center
    IF "Word_to_Shift" = 64 AND "Timer_1_done"  THEN
        "Stacker_Crane_Right" := False;
        "Timer_1_Start" := FALSE;
        "Word_to_Shift" := 128;
    END_IF;
END_REGION

```

```
REGION Step 8
    // Return back
    IF "Stacker_crane_Middle-Limit" AND "Word_to_Shift" = 128  THEN
        "stacker_crane_target_position" := 55;
        "Word_to_Shift" := 256;
        "Timer_1_Start" := TRUE;
    END_IF;
END_REGION

REGION Step 9
    // Reset
    IF NOT "Stacker_crane_Moving-x" AND NOT "Stacker_crane_Moving-z" AND "Word_to_Shift" = 256 AND "Timer_1_done" THEN
        "Capacitive_sensor_1" := FALSE;
        "Timer_1_Start" := FALSE;
        "Word_to_Shift" := 0;
        "waiting_for_crane_return" := FALSE;
    END_IF;
END_REGION

REGION Waiting FOR stacker TO get back TO center
    //Waiting until stacker gets free
    IF "waiting_for_crane_return" = TRUE AND "capacitive_sensor_2" = TRUE THEN
        "Roller_conveyor (6m)" := FALSE;
    END_IF;
END_REGION
```