Tampere University of Applied Sciences

# Developing warehouse management automation streamlining software

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International Business

**ABSTRACT**

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In the constantly changing landscape of industry, it's crucial to ensure that a company's operations are optimized. There are various methods to enhance performance in warehouse operations, one of which is the focus of this thesis: warehouse management automation. Specifically, this thesis delves into automating the calculation of drive load wheel circumferences for robots used in warehouse management. During their internship, the author developed software aimed at automating this calculation process, currently performed manually by the contractor company.

The primary goal of this thesis is to detail the development of software for automating the calculation of the drive load wheel circumference, streamlining the existing manual and time-consuming calculation process. Another objective is to demonstrate the importance of automation, alongside highlighting recent advancements in warehouse management automation. The additional goal lies in presenting a manual for both outlining the user experience in this thesis as well as for it to later potentially serve as a user manual for the employees at the contracting company.

The theoretical segment of the thesis examines the history and progression of automation within the warehouse management sector. It serves as the background for outlining the importance of automation in the field of warehousing. Qualitative research is conducted to document the author’s process of developing the drive load wheel calculation software, drawing practical insights from a case study.

The key outcome of this thesis is twofold: firstly, the practical development of the drive load wheel circumference calculation application commissioned by TP-Kunnossapito Oy. Secondly, a theoretical contribution is made through an overview of the user experience with the application, including written instructions and visual aids. This overview also serves as a user manual for future users and employees of TP-Kunnossapito Oy, guiding them through the step-by-step calculation process.

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Key words: e-commerce, entrepreneurship, online shop

**CONTENTS**

# 1 INTRODUCTION

In the constantly evolving industrial sector, it is important to keep a company's operations optimised. There are many approaches to achieving better performance when it comes to warehouse operations, one such approach is the focus of this thesis, and that practice is automation of warehouse management. This thesis specifically focuses on the automation of calculating the drive load wheel circumference of various robots that automate warehouse management. The author has spent their internship at TP-Kunnossapito Oy developing software that could be used to automate the process that is currently used for said calculation by the contractor company.

The objective of this thesis is to detail the development of a drive load wheel circumference calculating software that would automate the existing process of the said calculation. The purpose of this thesis is to create and implement the drive load wheel circumference calculation software that uses the Totally Integrated Automation (TIA) Openness Application Programming Interface (API), using both business and programming knowledge gained during the author's studies. The second purpose of this thesis is to outline the importance of automation in the current times, as well as in the recent past, and to outline the recent developments in the field of warehouse management automation.

The most important prerequisite knowledge for understanding this thesis is the understanding of TIA Portal and TIA Openness API. The TIA Portal is an engineering framework and a platform for programming and configuring automation systems. It's widely used in industrial automation for programming Programmable Logic Controllers (PLC), Human Machine Interface (HMI) devices, and other automation components. TIA Openness API is an API provided by Siemens in the TIA Portal ecosystem. It allows programmers to access and manipulate TIA Portal project data programmatically.

This is a practice based functional thesis. The data collection for this thesis is mostly of a qualitative nature, utilizing such data collection methods as content analysis where information is gathered from online sources together with literature, and additional information is gathered from the case study. In the practical part of the thesis, the experimental method consists of experimentation with the capabilities of the TIA Openness API. The primary idea of this experiment case study is to learn from the experience of the calculation application development process, documenting all the steps of said application development.

## 1.1 Thesis background

The company that provided the author of this thesis with the internship opportunity and ordered the software that is at the core of this thesis is TP-Kunnossapito Oy which is an industrial company that specializes in installing, repairing, and maintaining industrial machinery for factories, warehouses, and any other enterprise in need of industrial machinery. As an International business major the author wishes to detail their experience developing and implementing the said software, communicating and working with industry specialists, as well as expanding their knowledge about warehouse management and overall automation and its effects on business operations.

This thesis provides a full breakdown of the drive load wheel diameter calculation process using the software developed,  in addition to serving as the documentation of the entire calculation application development process. The focus of this thesis is less on the programming aspect of creating the application, and more on outlining the entire development process from collaboration with the final user to learning the basics of TIA Portal.

## 1.2 Theoretical framework

The theoretical framework portion of the thesis talks about concepts necessary for understanding the thesis correctly. The following concepts are relevant to this study because they provide both the background and current context of warehouse automation.

TIA Portal is used in this thesis in the learning stage of the application development to understand the TIA Portal ecosystem. It is also relevant since it is used by the contracting company to program PLCs, therefore dictating that the application developed as the core of this thesis needs to communicate with TIA Portal and projects within. Thorough knowledge of TIA Portal is therefore necessary to locate and manipulate parameters in the TIA Portal projects.

TIA Portal, which is used for Totally Integrated Automation, is Siemens's all-in-one engineering platform, revolutionizing the automation landscape. It simplifies complex processes and optimizes machine manufacturing by integrating various components like PLCs, HMI screens, Variable Speed Drives, and Servos into a single software package. (Automationfair 2023.)

In the past, managing these components meant grappling with multiple software platforms, but TIA Portal changed the game by offering a unified interface. This consolidation not only enhances efficiency but also introduces new features like multi-user support and power management, making industrial automation projects more streamlined and accessible than ever before. (Automationfair 2023.)

The TIA Openness API is used in this thesis extensively, as it is the only way to retrieve TIA Portal project properties and manipulate them programmatically. Seeing that the entire purpose of the application as ordered by the contact person at TP-Kunnossapito Oy is to interact with TIA Portal projects and properties within, TIA Openness API is an integral part of both the project and this thesis.

Siemens TIA Openness represents an API built into the TIA Portal, which allows one to interact with the platform through custom applications. Despite this inclusion, Openness has yet to see widespread adoption, mainly because programmers are reluctant to adopt another programming language, namely C#, along with their skills in PLC programming. (Smith 2019.)

TIA Openness has several benefits that can dramatically increase the effectiveness of PLC development. A notable function is the development of modular code designed for devices, which automatically provides application-specific modifications. By defining basic templates, users gain the ability to perform complete tasks without PLC and HMI programming skills, simplifying implementation and providing greater accessibility. (Smith 2019.)

Object-oriented programming is an unavoidable subject in the case of this thesis. According to Alexander Gillis (2021), object-oriented programming is a computational programming model that structures software development based on data entities, known as objects, rather than focusing solely on functions and procedural logic. An object, in this context, embodies a data structure comprising distinctive characteristics and functionalities.

During the learning phase of the application development, considerable effort was made to transition to the usage of classes and to object-oriented programming overall. Since the calculator is complex, programming it without the use of object-oriented programming would be very tedious and time-consuming which pushed the author towards the use of classes, making object-oriented programming a pivotal part of this project as well as this thesis.

# 2 WAREHOUSE AUTOMATION

This section defines the background of the thesis topic, said background being an overview of the progress in the field of warehousing and warehouse management. It defines the history of warehousing as well as lists the types of robots that are most commonly used for automating warehousing operations. Additionally, it expounds on the impact and importance of using robots in automating repetitive tasks in the scope of warehouse management and warehousing.

## 2.1 Evolution of warehouse management: from manual to robotic systems

The warehousing system has undergone a substantial transformation, evolving from traditional storerooms to integrated and automated systems. The introduction of Industry 4.0 also known as the fourth industrial revolution in 2011 has propelled the concept of smart warehousing, aiming to enhance overall performance by reducing manual labor and improving precision. Despite the potential benefits, a significant portion of warehouses worldwide remain either manual or employ low-level automation due to high initial investments and a lack of IT knowledge. (Kumar, Narkhede & Jain 2020.)

According to Kumar S., Narkhede B. & Jain K.(2020), the three decades of warehouse evolution are described as 1990-2000, 2001-2010, and 2011-2019 decades (Picture 1). These decades are described below in detail.

From 1990 to 2000, organizations globally expanded warehousing, driven by Liberalization, Privatization, and Globalization (LPG) economic policies. Strategic decisions were made intuitively, emphasizing cost-effectiveness through periodic reviews of layouts and operations. Challenges included slow inventory turnover and meeting dynamic customer demands, leading to costly services and profit margin pressures. Warehouse managers grappled with optimizing size, configurations, and policies. To meet customer demands, warehouses provided costly services, impacting profit margins. Warehouse managers encountered difficulties determining optimal size of the warehouse, external as well as internal settings, and standard policies for various processes. As time progressed, numerous warehousing practices and customs were introduced, incorporating measures to assess performance, shifting the focus from trying to increase productivity to managing the inventory more efficiently.

From 2001 to 2010, increased attention was directed towards supply chain warehouses, and crucial inventory storage points for enhancing customer service. The practice of inventory management persisted, resulting in the closure of smaller warehouses or their transformation into larger facilities. Research was concentrated on inventory management techniques, processes, batching, and order selection. It aimed to develop scientific and rational warehouse planning based on objectives, demand forecasting, business processes, and inventory.

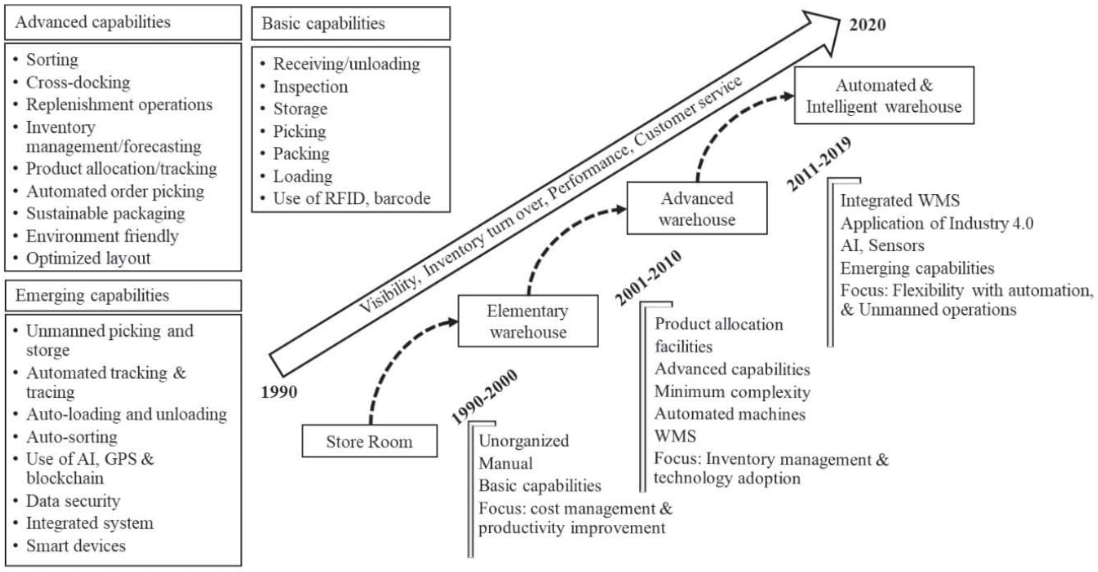
By the mid-decade, warehouse analysis narrowed down to specific operations, with a heightened focus on order selection compared to other processes. The expanding e-commerce market introduced new challenges, such as selecting a faster storage/retrieval system, improving inventory visibility, and enhancing operational efficiency. Furthermore, efforts were directed in the direction of partially automated warehouses with desired capabilities made possible with the help of machines, flexible manufacturing systems, and ICT to enhance overall warehouse performance.

From 2011 to 2019, significant transformations occurred in warehouse management systems to address the challenges of the VUCA (Volatility, Uncertainty, Complexity, Ambiguity) business environment propelled by intense competition. The hasty expansion of the electronic commerce market pushed organizations to establish a flexible and adjustable warehouse systems capable of handling faster lead times, flexibility in the quantity of orders, a wide variety of products, fluctuating demand, and responsiveness in real-time.

The advent of Industry 4.0, powered by technologies such as IIoT, ICT, Big data, Autonomous robots, Cloud computing, Simulation, Cyber-physical systems, and AR, created substantial possibilities for warehouse management. As a result, the warehousing research focus shifted towards harnessing these possibilities. Automatic pallet stocking and detachment technology, advanced material handling systems, including improved AS/RS (Automated Storage and Retrieval Systems), and AGV systems, utilized Industry 4.0 technologies and came to be central to warehouse research. These technologies employed unmanned transportation modes within aisles to facilitate order picking operations.

The implementation of IT-enabled picking technology with real-time data sharing and transparency capabilities significantly improved accessibility. Integrated facilities for storage, batching, packaging, and sorting, coupled with the establishment of pick-to-light, virtual reality systems, AR, voice navigation, and drone-based practices, streamlined warehouse operations and enhanced picking and packing accuracy. The incorporation of integrated omnichannel strategies, ergonomically designed automated picking workstations, human-machine interaction systems, and AI captured the attention of warehousing researchers.

While the focus of this decade was on implementing modern technology, control, and automation, there is a noticeable absence of controlled studies on the use and benefits of Industry 4.0 technologies in warehouse management. Additionally, there is a scarcity of skilled and experienced workers for advanced warehouses, highlighting the need for significant investment in hardware, software, infrastructure modifications, and the development of skilled personnel in technology-enhanced warehouses




PICTURE 1. Proposed conceptual framework of warehousing from an evolutionary lens. Adapted from Kumar S., Narkhede B. & Jain K.(2020)

### 2.2 The impact of robotics on warehouse efficiency

This section delves into the transformative impact of robotics and automation on warehouse operations, highlighting the benefits and challenges associated with these technologies. It discusses the rise of robotics, the role of artificial intelligence (AI) in warehouse optimization, and future trends, emphasizing key features and advantages, the impact on efficiency, and the ongoing technological revolution in logistics.

Warehouses, crucial components of global supply chains, are undergoing a significant transformation with the integration of robotics and automation technologies. This adoption brings increased efficiency, improved accuracy, cost savings, and enhanced safety to warehouse operations.

Benefits of Robotics and Automation in Warehouses: in warehouse operations, robotics, and automation enable precise and swift handling of repetitive tasks, resulting in heightened picking efficiency. Programmed for high precision, robots reduce errors, enhancing order fulfillment accuracy and customer satisfaction.

Despite initial investment costs, automation leads to long-term savings, with a reported decrease in operating expenses by companies. Automation also contributes to enhanced workforce safety by reducing hazards, automating tasks, reallocating workers, and minimizing injuries.

AI-powered systems further revolutionize warehouse operations by enabling intelligent decision-making and adaptability. Machine learning algorithms analyze data, optimizing processes, and predicting demand, leading to even greater efficiency gains.

Challenges in implementing robotics and automation include initial costs, workforce adaptability concerns, complex integration with existing systems, and the need for proactive maintenance and reliable technical support. Thorough cost-benefit analysis, flexible pricing models, transparent communication, training, engaging experienced consultants, and proactive maintenance strategies are crucial for addressing these challenges.

Future trends include the development of collaborative robots (Cobots) designed to work alongside humans, the adoption of autonomous mobile robots (AMRs) for flexible and dynamic operations, leveraging big data analytics for optimized inventory management, and integrating the Internet of Things (IoT) for real-time data communication and predictive maintenance.

The integration of robotics and automation technologies presents a transformative opportunity for warehouses, offering efficiency, accuracy, and cost savings. As the logistics industry evolves, staying updated on emerging trends and overcoming challenges will be crucial for businesses aiming to thrive in the modern supply chain landscape.

### 2.3 Automated warehouse robots: types and benefits

Recent data indicates that approximately 20% of warehouses have implemented some form of robotics, with Amazon boasting over 500,000 active robots in its facilities alone (Young 2023). This data highlights the current reality of warehouse robots being an integral part of today's supply chain, rather than a futuristic concept.

The increasing popularity of automated warehouse robots in modern warehouses can be attributed to various factors. Utilizing robots in warehouse processes helps diminish dependence on human labor, resulting in a facility that is more cost-effective, productive, and safe. These advantages are just a fraction of the overall benefits offered by automated warehouse robots.

To fully comprehend what automated warehouse robots entail and how they can optimize warehouse operations, it is essential to delve deeper into their functionalities. According to Erhan Musaoglu, 2023: here are key takeaways to grasp about automated warehouse robots:

**Minimal Human Intervention**: Automated warehouse robots are designed as robotic systems to carry out warehouse tasks with minimal or no human intervention. This aspect significantly reduces the need for manual labor and minimizes human error, contributing to more efficient and reliable operations.

**Variety of Solutions**: Different warehouse robot solutions exist, and selecting the right one for one’s facility depends on one’s specific warehouse processes and objectives. The choice of robots must align with the nature of tasks, the layout of the warehouse, and the business goals to achieve optimal efficiency.

**Types of Warehouse Robots**: Common types of warehouse robots include automated mobile robots (AMRs), goods-to-person (G2P) robots, drones, and others. Each type of robot is better suited for different types of jobs, utilising several types of robots in one facility can result in better efficiency.

**Operational Continuity**: Automated robots have the capability to keep one’s warehouse operational 24/7, enhancing productivity and profitability. Continuous operation ensures that tasks such as sorting, packing, and transportation can be carried out without interruption, thereby speeding up the entire supply chain process.

**Integration with Warehouse Management Systems (WMS)**: The integration of a comprehensive warehouse management system (WMS) is crucial for maximizing the potential of warehouse robots. A WMS facilitates the coordination and control of all robotic activities, ensuring seamless operations, accurate inventory management, and efficient order fulfillment.

Automated warehouse robots are engineered to execute a range of warehouse operations, including picking, packing, sorting, storing, and labeling, while minimizing human involvement. These robots rely on sensors and cameras to map and traverse warehouse environments, equipped with arms for handling goods.

In collaboration with warehouse management systems (WMS) like Logiwa, modern automated warehouse robots leverage data from connected systems. The WMS assigns tasks and programs the robots to autonomously complete processes. Monitoring and tracking the performance of warehouse robots can also be efficiently managed through the WMS.

There are four main benefits of warehouse robots. These benefits are listed below:

**Cost reduction:** unlike human workers who require salaries and benefits, robots operate without wages, offering a cost-effective solution to reduce warehouse operating expenses.

**Enhanced efficiency:** warehouse robots, being tireless, reduce the likelihood of errors associated with human fatigue. Automating repetitive or complex tasks improves efficiency and productivity.

**Improved safety:** autonomous mobile robots can handle heavy goods without human intervention, decreasing the risk of accidents involving dangerous equipment or heavy items.

**Real-time data and insights:** automated robots provide actionable insights for optimizing warehouse operations. Integration with a WMS like Logiwa allows easy access to the latest data and insights through a user-friendly dashboard.

According to Erhan Musaglu (2023), there are different types of automated warehouse robots. These robots play key roles in optimizing warehouse operations.

**Automated guided vehicles (AGVs)**

AGVs are mobile robots programmed to transport inventory within warehouses. Operating autonomously along predefined routes using lasers, sensors, or magnets, AGVs offer a safer alternative to forklifts by minimizing human intervention.

**Automated mobile robots (AMRs)**

Unlike AGVs, AMRs freely navigate warehouses, retrieving and delivering inventory. Their autonomy and flexibility make them easily adaptable to changes in warehouse layouts, enhancing operational efficiency.

**Picking & packing robots**

Robotic arms programmed for order retrieval and preparation, equipped with advanced sensors and algorithms. Picking and packing robots boost warehouse productivity by processing orders continuously, day and night, surpassing human speed and efficiency. (Universal Robots 2022.)

**Co-Bots (collaborative robots)**

Designed to work alongside human workers, co-bots assist with tasks such as picking, lifting, quality control, packing, and shipping. Equipped with sensors to prevent collisions, co-bots enhance accuracy in order fulfillment.

**Palletizing robots**

Automate stacking and organizing inventory onto pallets, optimizing storage space, improving safety, and minimizing the risk of damaged goods. Palletizing itself is the practice of moving products onto a pallet for further transportation or storage.

**Automatic storage & retrieval system (ASRS) robots**

ASRS robots automate the storage, retrieval, and handling of warehouse goods, optimizing storage space and improving inventory efficiency with methods like FIFO or LIFO. First-Out (FIFO) method, the assumption is that the earliest inventory or the first unit entering inventory is the first to be sold. The Last-In, First-Out (LIFO) method assumes that the last or most recent unit added to inventory is sold first. (Tardi 2023.)

**Goods-to-person (G2P) robots**

Retrieve items from inventory and deliver them to packers for order fulfillment, minimizing human walking time and maximizing efficiency. Such robots are commonly used in e-commerce fulfillment centers.

**Drones**

Unmanned aerial vehicles are used for mapping, surveillance, tracking items, inspecting inaccessible areas, updating inventory records, verifying stock levels, and monitoring workers and large spaces in warehouses. These are not to be confused with commercial drones which require direct human control, while the drones in question are mostly autonomous.

These automated robots collectively contribute to enhancing warehouse operations, providing efficiency, safety, and adaptability. All of the above contributes to the ever-growing interest towards automation and robots in particular.

### How warehouse operations can be improved with the help of robots and automation

Criticism is frequently directed at the warehousing process because of its related costs, leading some individuals to contemplate the outsourcing trend as a means of sidestepping the intricacies involved in analyzing in-house logistics expenses. Apart from evident costs like inventory, technology, labor, and operations, stock-keeping introduces challenges and indirect costs. To achieve efficient goods distribution systems with minimized stocks, structured and transparent processes are necessary, facilitated by Warehouse Management Systems (WMS). A crucial aspect of an efficient WMS involves building confidence in the management and control system, thereby reducing excessive safety stocks caused by managerial uncertainty. Improving data security and transparency in WMS fosters continuous system optimization, enhancing the controllability and manageability of processes, and increasing response time and flexibility. Interfaces to subordinate systems enable adaptability to changing structures. (Hompel & Schmidt 2005.)

Warehouse operations can be significantly improved with the integration of robots and automation. Here are several ways in which these technologies can enhance efficiency, accuracy, and overall productivity in a warehouse:

### More on Palletizing robots and their impact

Robotic palletizing involves utilizing industrial robots to arrange and stack products onto pallets for shipping. A variety of robots can perform palletizing tasks, with the most prevalent method being the use of specialized palletizing robots designed for the rapid handling of large, heavy items. (Owen-Hill 2020.)

Palletizing robots serve the dual purpose of alleviating humans from tedious and physically demanding tasks that involve complex auxiliary tools, leading to prolonged processing times. In contrast to fully automated specialized facilities, these robots offer greater flexibility and cost efficiency, especially when dealing with smaller workloads. Common robot types employed for such tasks include portal and articulated arm robots (Hompel & Schmidt 2005). Palletizing robots come with a robotic arm and a product gripper, allowing them to lift and position items with precision, adjusting seamlessly to variations in size and weight. These robots employ sensors and advanced programming to assess the placement of each item, ensuring a secure arrangement. Through the automation of these tasks, these robots not only save operators time but also minimize the risk of item damage and optimize storage capacity. (Modula 2023.)

**Increasing order-picking efficiency**

Robots play a role in order-picking tasks, either mounted on rack feeders to retrieve items from shelves or working in distinct areas where they pick larger standardized units from stacks of pallets. The efficiency and performance of these robots are significantly influenced by the quality of the pick-up units provided. The more accurate the provision of these units, the smoother the integration of the robot into the overall system becomes. However, these systems impose significant demands on the precise positioning, decollation, and handling of articles, leading to time-consuming and expensive processes. (Hompel & Schmidt 2005.)

**Logistics efficiency**

Efficient logistics and warehouse management are crucial aspects of a company's supply chain. Streamlining warehouse operations not only cuts costs but also enhances customer satisfaction through prompt and precise deliveries. Mobile robots have emerged as valuable tools, enabling automation in logistics. This includes warehouse management software, automated conveyor systems, and versatile mobile robots capable of tasks like transporting goods and organizing inventory. These autonomous mobile robots operate tirelessly in collaborative environments, reducing errors, cutting costs, and boosting warehouse productivity. (Robotnik 2023.)

For example, robots that increase logistics efficiency in WMS, are Automated Guided Vehicles (AGVs) and Automated Guided Carts (AGCs).

AGVs are robotic systems used in warehouses, which adhere to predetermined paths with the aid of sensors, markers, and lasers to ensure accurate navigation. In contrast to Autonomous Mobile Robots (AMRs), AGVs rely on fixed routes and guidance from warehouse operators for their operation, limiting their adaptability to unexpected changes in the environment.

AGCs are robots designed for inventory transport, utilizing predefined paths. Equipped with magnetic tape, radio frequency identification (RFID) tags, and sensors, AGCs navigate the warehouse and detect obstacles. Unlike AGVs, AGCs are constrained by their lower profile and smaller chassis, making them suitable only for carrying lighter loads. (Modula 2023.)

With the rise of automation in the industry, the call for more modern warehouses is growing again. While the benefits of automation are widely recognized, justifying changes from current methods can be challenging. Initially, the high cost of implementing a fully automated solution often discourages companies from participating. To justify an investment in automation, companies need to understand its overall impact on their business. According to JR Automation (2023), here are five ways automation can drive business benefits, positively impacting the bottom line:

**Addressing staffing challenges:** Whether struggling with recruitment or layoff issues or facing a shortage of skilled workers, staffing constraints can hamper productivity path Automation can address gaps, enabling business units to complete critical tasks when manpower is scarce.

**Reduce operating costs**: Automation reduces the possibility of material misuse or damage, reduces inventory inconsistencies, and reduces picking and packaging errors in a way that saves time and money and also speeds up tasks that would otherwise take a lot of time for people to do.

**Streamlining inventory management:** The cost of moving and storing inventory can be significant, especially as order volume increases. Manual inventory management requires hours of operation, while robotic systems such as AGV or AMR ensure consistent and continuous movement of materials, reducing labor-intensive tasks Increase efficiency and productivity: By outsourcing repetitive tasks to automation, employees can focus on complex and interesting tasks, increasing productivity. Automation ensures a robust workflow, with round-the-clock capacity, and enables faster order processing and fulfillment.

**Reducing safety risks:** Automation can replace humans in activities that are susceptible to injury or ergonomic stress. Work involving repetitive moving or heavy lifting poses a risk to personnel, which can be reduced by automation, reducing the possibility of occupational injury and to ensure smooth warehouse operations

**Reducing errors:** The speed and accuracy of order selection greatly affect customer satisfaction. Automating processes improves pick rates and reduces the incidence of misselections, avoiding errors caused by human fatigue. Unlike humans, robots are designed for accuracy and precision.

In conclusion, automation has the potential to transform warehouse operations, if implemented correctly. By using data and automation strategically, significant productivity improvements can be achieved. Our team is ready to guide one through the process, helping one choose and integrate the right automation solutions that fit one’s business needs.

# 3 OVERVIEW OF THE PROBLEM AND ITS IMPORTANCE

The problem itself as well as the importance of the project were relayed to the author in the form of an interview before signing up for the initial internship. The following section is done in the form of a case study documenting the project as well as justification for its development.

## 3.1 The problem in warehouse automation efficiency

The main problem, as was stated by the hiring company, was the inefficiency in the process of calculating the drive load wheel diameter of the robots. Additionally, there was a wish to simplify creating projects that define the controls of the robot perhaps by creating an easily applicable template, however, this part of the overall project got stripped later on into development.

### 3.1.1 The problem for the robots

The problem for the robots was that whenever a change would occur there was a dire need to calculate the drive load wheel diameter in the project controlling the robot. The change mentioned could be anything from old chains or belts being replaced which would change the diameter because the new chain or belt in good condition would sit differently on the machine to new parts being introduced or simple wearing down of existing parts.

The dire need for recalculation of the drive load wheel circumference comes from the need for precision as a mistake in the warehouse management processes can be catastrophic leading to losses in profit or even human health risks.

### 3.1.2 The problem for the automation experts

The always persisting need for drive load wheel circumference calculation presents a problem for the efficiency of the automation department as there is a constant need to go to the factory and recalculate the drive load wheel diameter. This process is time-consuming for several reasons, those being: the need to get dressed in protective equipment every time and then back into comfortable clothes, walking distance to the factory from the office and back, the testing itself and calculation itself, the manual retrieving of the parameters for calculating the new diameter, and manual rewriting of the diameter and possibly other changed parameters.

The benefits of automating such time-consuming and repetitive tasks can show both in the company operations efficiency itself, but also in the employee morale and outlook. The company benefits greatly from automating tedious, potentially hazardous, and time-consuming tasks, as it frees up time for employees to work on more important and personally satisfying tasks. In addition, it is important to mention that repetitive tasks can be potentially completed faster and more efficiently when automated, directly benefitting the company by improving operations efficiency. The employees however benefit from menial task automation in a way that is different from the organization as a whole, because these tedious tasks are not engaging the employee who is forced to complete them may lose morale, which can lead to a decrease in efficiency. Automating these tasks allows the employee to focus on more engaging tasks that result in higher morale and lead to increased performance and overall long-term well-being of the employee, which yet again benefits the employer. (Partida 2022.)

## 3.2 The importance of the project for warehouse automation efficiency

The problem that is being solved by this project is the need for manual retrieval of parameters to calculate the drive load wheel diameter, calculating it, and manual writing of the new parameters. The idea was originally to create a program that could open the TIA Portal project in which the robot control parameters or PLC parameters are located, find and retrieve the needed parameters, calculate the current drive load wheel diameter, and then with the input from the user calculate the new diameter, afterwards it would write adjusted parameters back to the project. Additionally in the beginning there was the idea of incorporating a “project blueprint” functionality, making it possible to speed up the new project creation process by applying a blueprint of the most common parameters and settings, this idea was however scrapped later into development.

This project would speed up the drive load wheel circumference calculation process significantly due to the large number of parameters that needed to be located and interacted with every time. The search among thousands of parameters in the TIA Portal is simply time-consuming resulting in the need for a solution, which came in the form of the application developed as the topic for this thesis. Additional time saved by having the app do all the calculations automatically is also appreciated.

The result and importance of this project can not be overstated since the time saved can instead be used to develop further projects for automating warehouse management systems and robots. The overall efficiency increase of the automation team is sure to lead to improvements in performance.

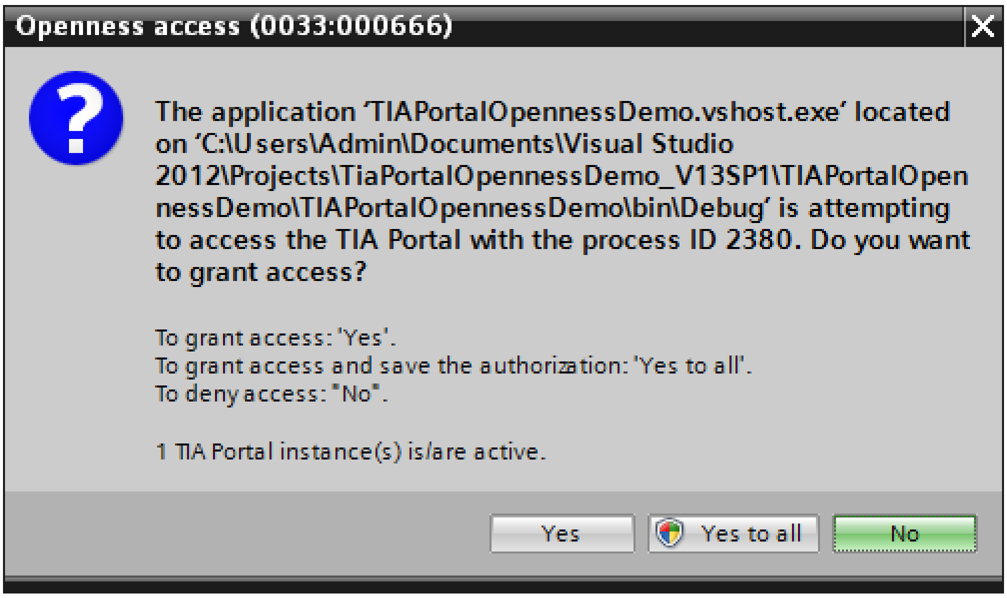
After all increased operational efficiency goes with reducing errors, in this case by removing the human factor from copying and rewriting, and with reducing errors, the time required for completing tasks decreases. In addition to reducing errors operational efficiency can be achieved by reducing the need for manual labour, in the case of this thesis it is the entire core of the project to reduce manual labour which goes hand in hand with increasing operational efficiency. Efficiently and precisely functioning equipment means additional operational efficiency as well as reduced need for additional adjustments, in this project it means that accurate calculation removes the need for recalculating again soon after. (KPI Solutions n.d.)

### 3.2.1 Project’s intended use

The program was initially supposed to have two main functions, 1st. being the calculation of the drive load wheel diameter and 2nd. being the creation of new projects with the help of perhaps pre-made blueprints or libraries. the uncertainty about the second intended functionality comes from the fact that it never came to be as during the program development process it was decided that it would be unnecessary to invest heavily into developing the feature, at least in the current state of affairs.

The program was to be used by any personnel attempting to calculate the robot’s drive load wheel, perhaps after a part replacement or upon a new robot installation or a plentitude of other scenarios harbouring the need for drive load wheel calculation. The personnel is then to connect to the robot or part in question and copy its project to their machine, then the person is to start the program and the rest of the experience will go as follows:

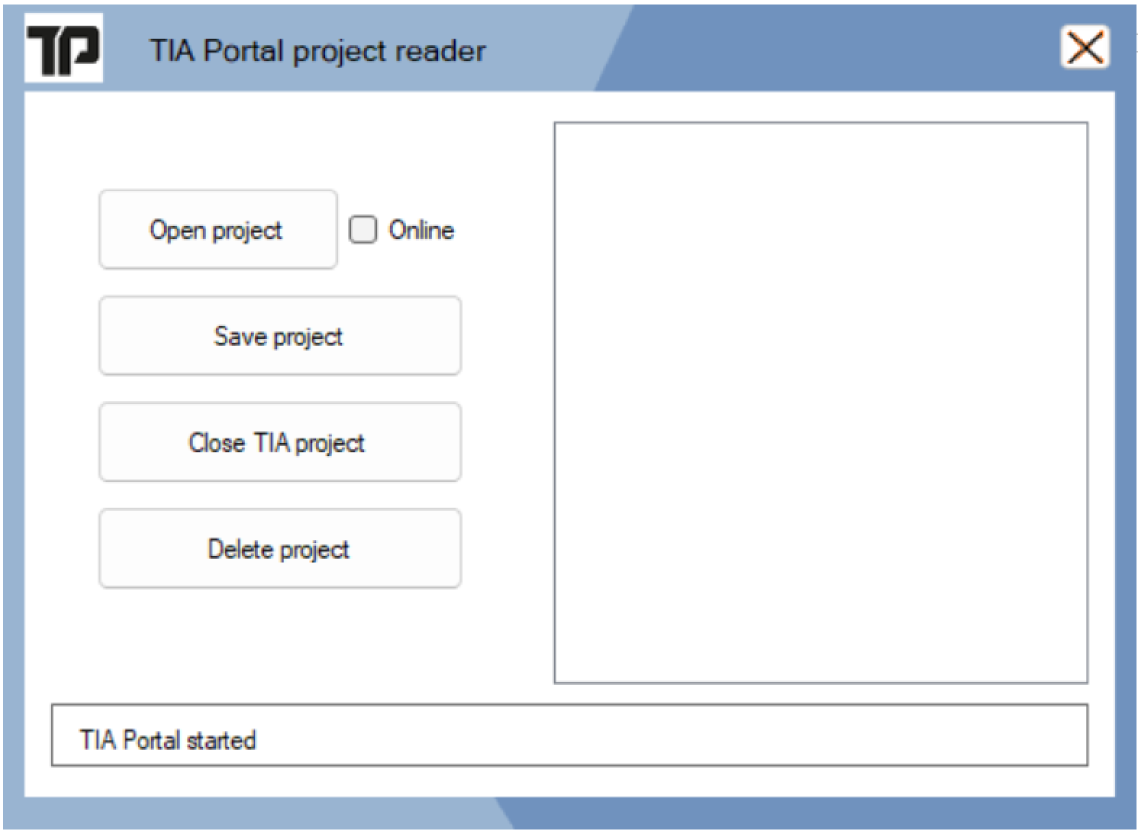
On launch, the user may encounter a notification as follows:




PICTURE 2: Screenshot of the notification that appears when trying to access a TIA Portal project with TIA Openness API (Siemens 2021).

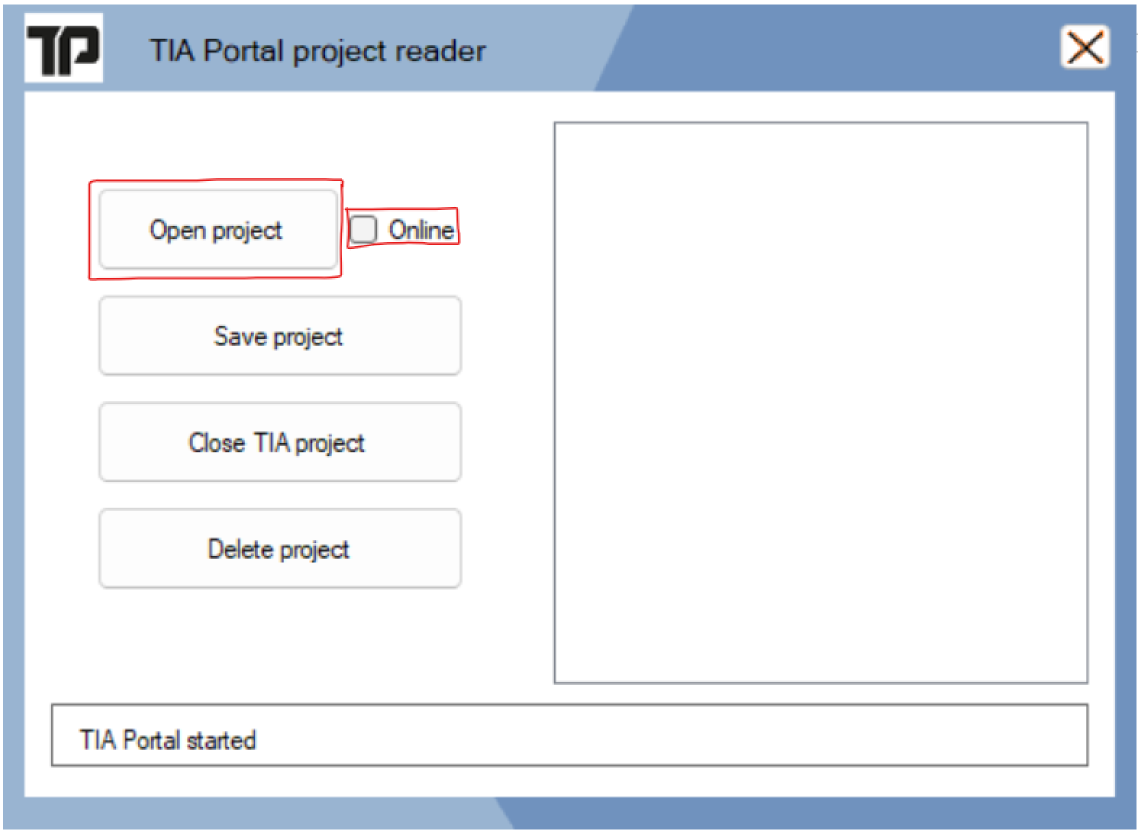
As is evident from the screenshot the TIA Openness API needs to be granted access to access the TIA Portal programmatically. Pressing “No” will not allow said connection resulting in the shutting down of the application. Pressing “Yes” or “Yes to all” however will result in the establishment of the connection to the TIA Portal and the proper starting of the application.

Upon program start the user will see the following interface (Picture 3).



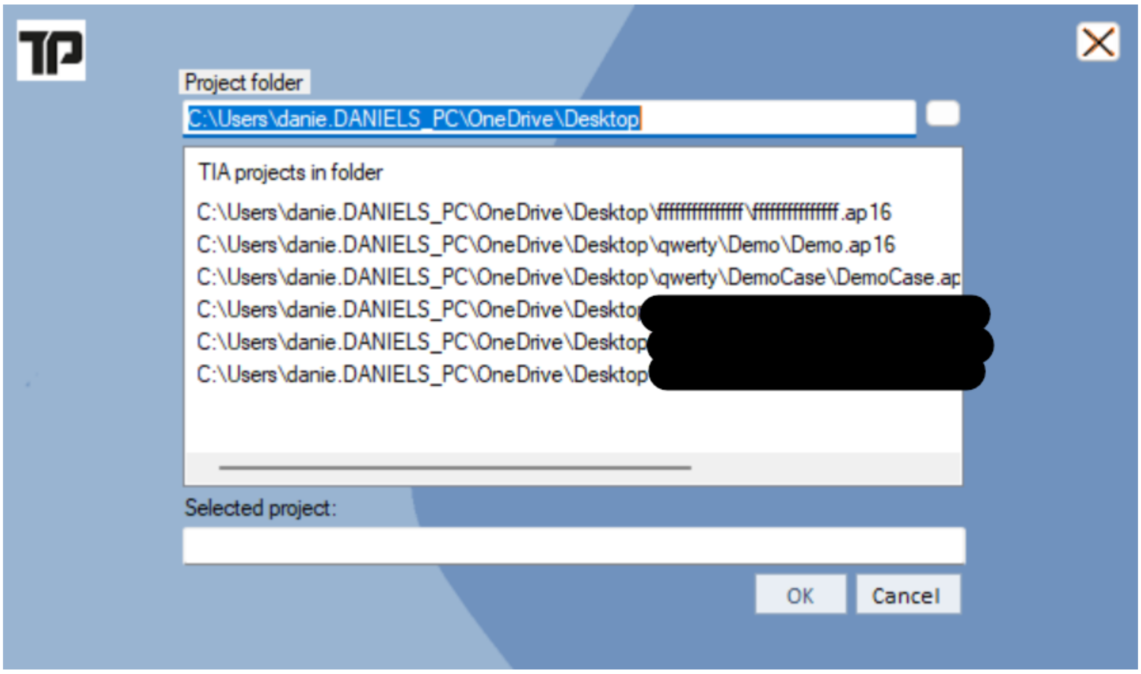

PICTURE 3: Screenshot of the main interface window.

Press the “Open project” button (before opening the project a choice needs to be made whether the edit is going to be made online or offline, the choice can be made simply by ticking the “Online” tick box) (Picture 4).



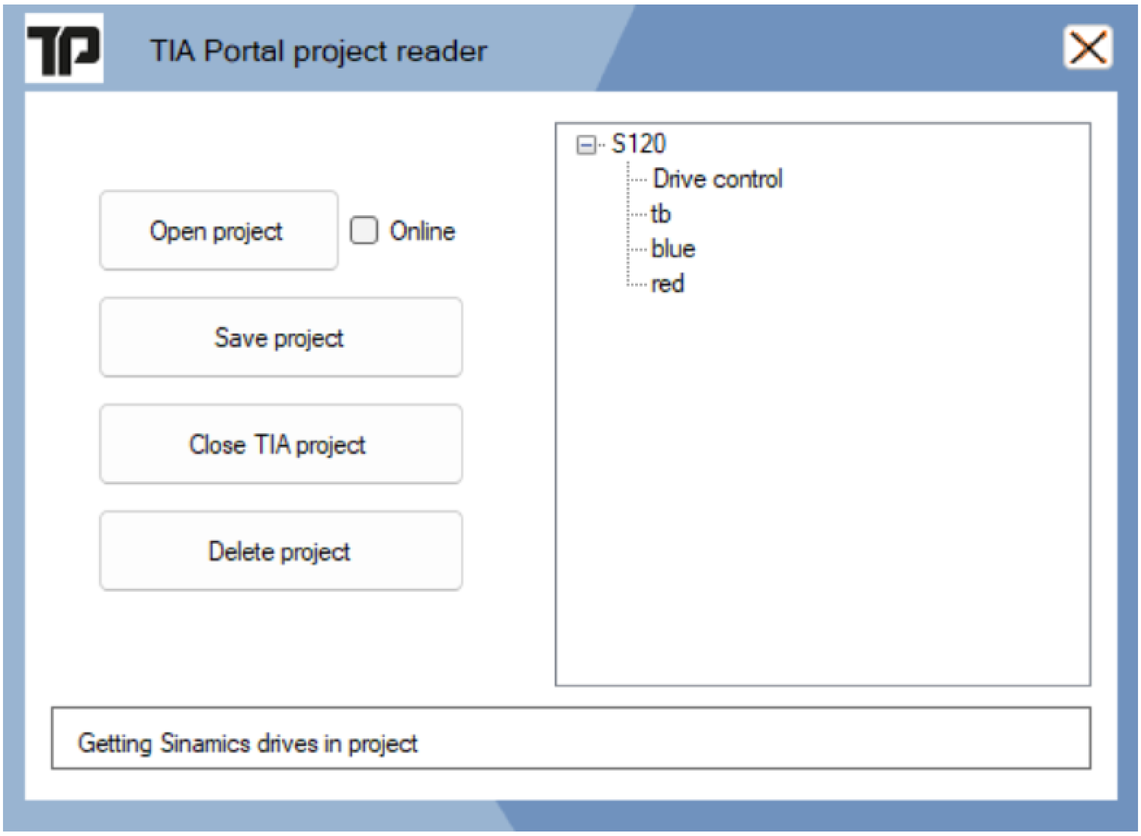

PICTURE 4: Screenshot of the main interface window showing how to open the project selection window.

Select the newly copied project (if the program has not been used previously on this machine then the project folder needs to be specified by pressing the “Project folder” button and navigating to the desired folder) by clicking on the project and then clicking the “OK” button (in case of this visual presentation the default “Demo” application was chosen to avoid sharing sensitive employer information) (Picture 5).



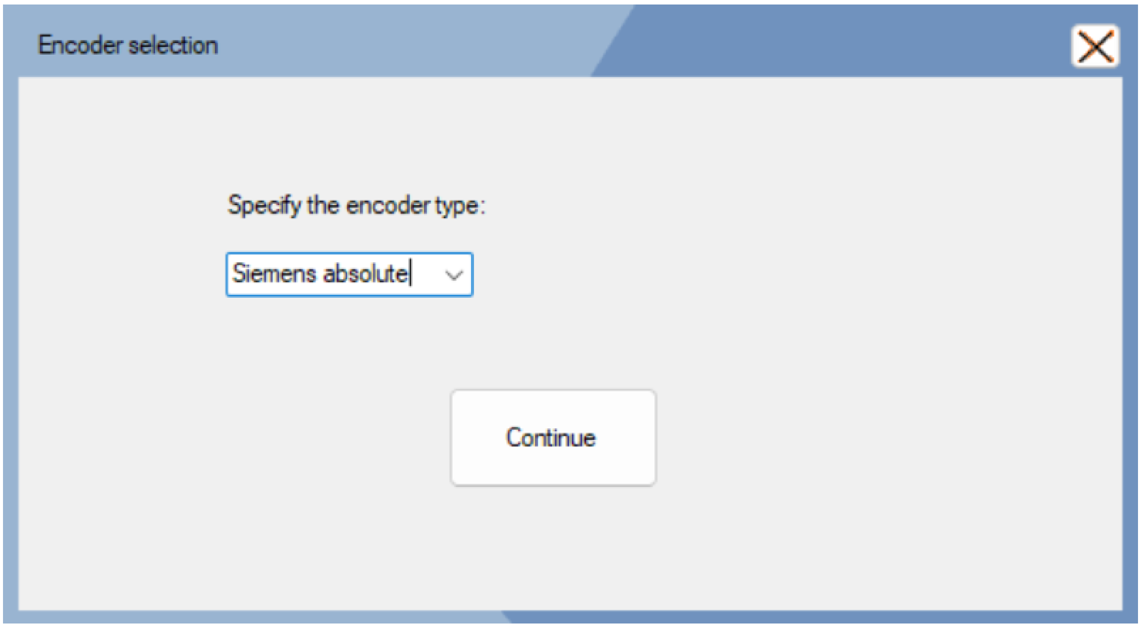

PICTURE 5: Screenshot of the “Project selection” window.

Navigate to the desired drive object in the tree (in this case it was “blue”) and click on it (Picture 6).



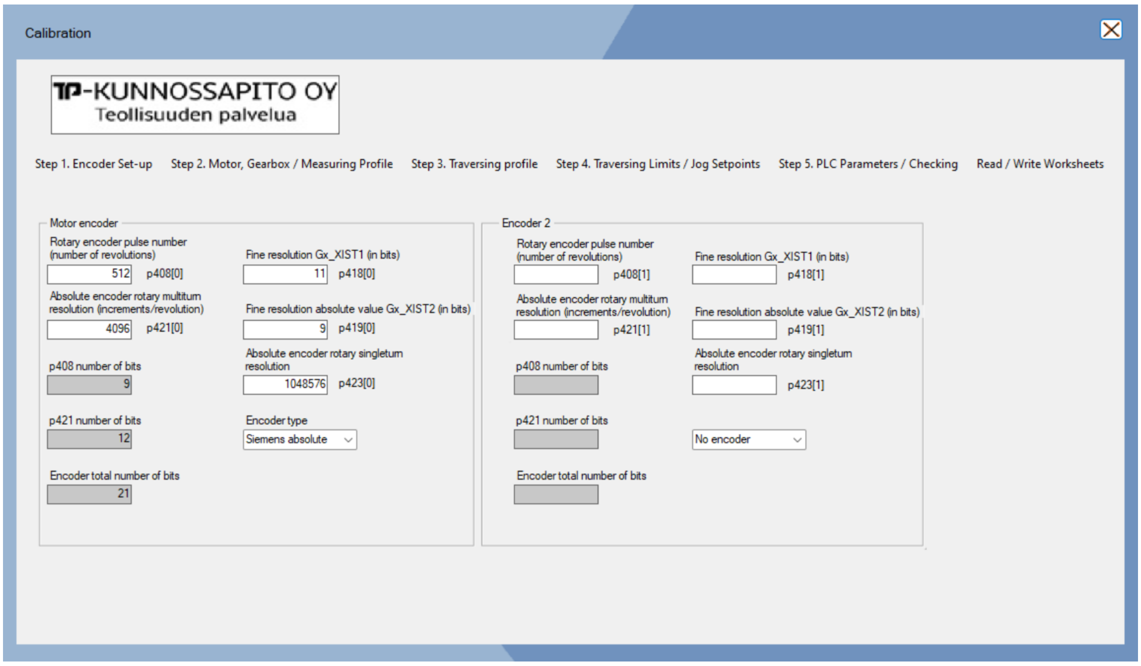

PICTURE 6: Screenshot of the main interface window after the project has been opened.

Select the encoder type of the drive object (in case of 2 encoders the program will ask to choose 2 encoder types), then press “Continue” (Picture 7).

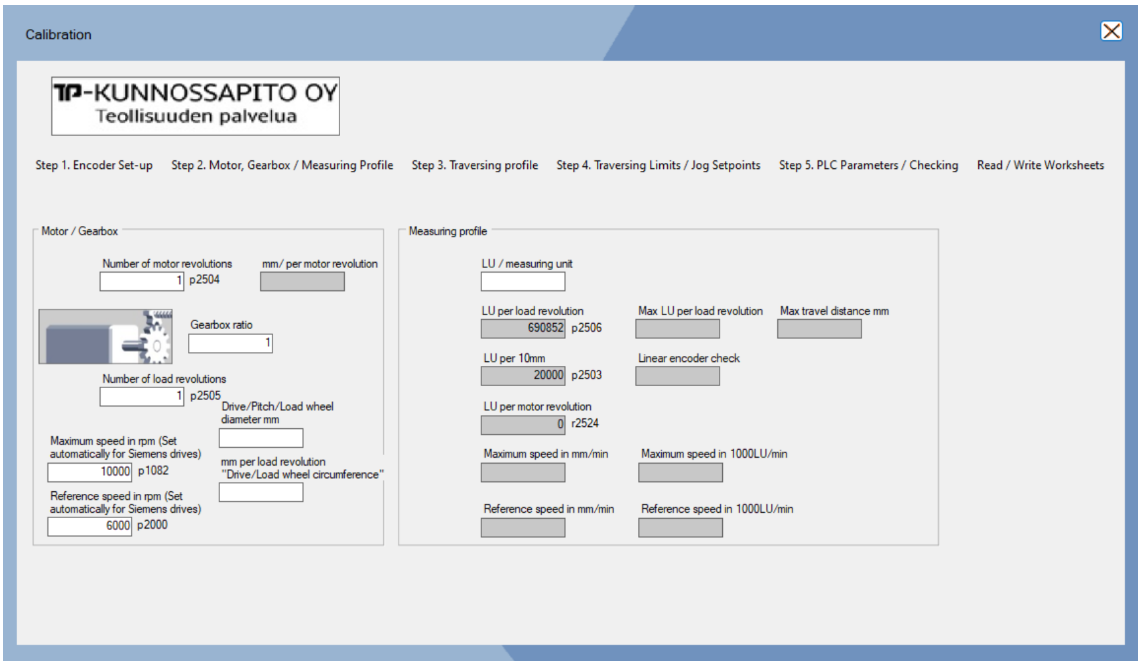



PICTURE 7: Screenshot of the “Encoder selection” window.

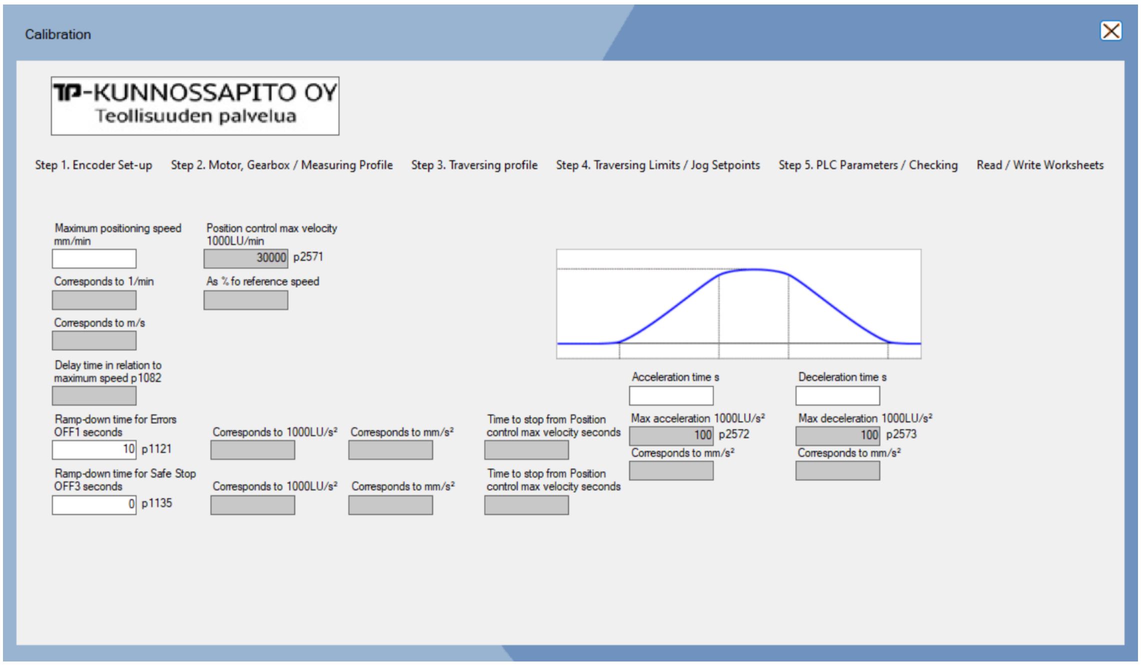
The following interface will open with all the programmatically accessible values automatically copied directly from the project. Here the user would need to fill in the programmatically inaccessible values.



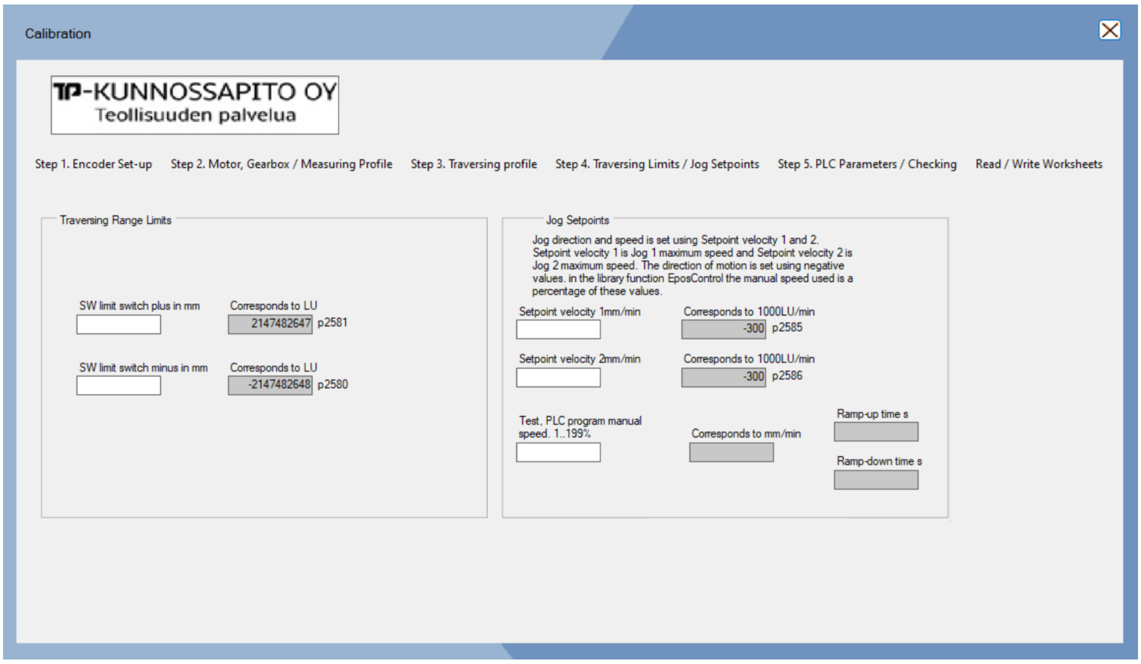

PICTURE 8: Screenshot of the “Encoder Set-up” page of the calculation interface.



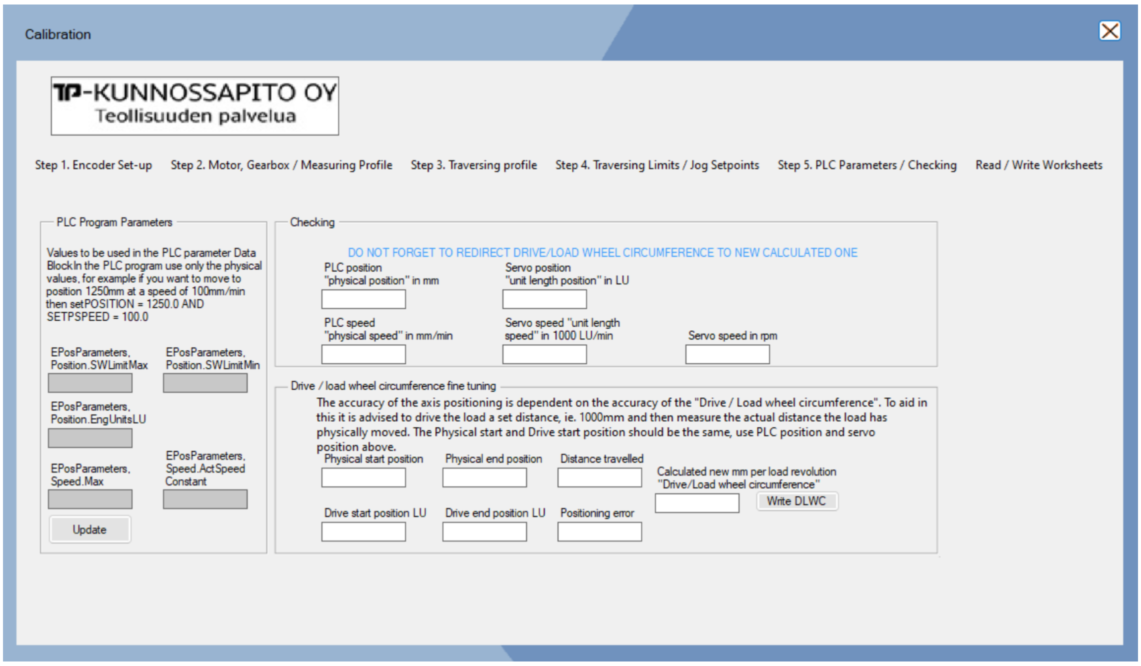

PICTURE 9: Screenshot of the “Motor, Gearbox / Measuring Profile” page of the calculation interface.




PICTURE 10: Screenshot of the “Traversing profile” page of the calculation interface.



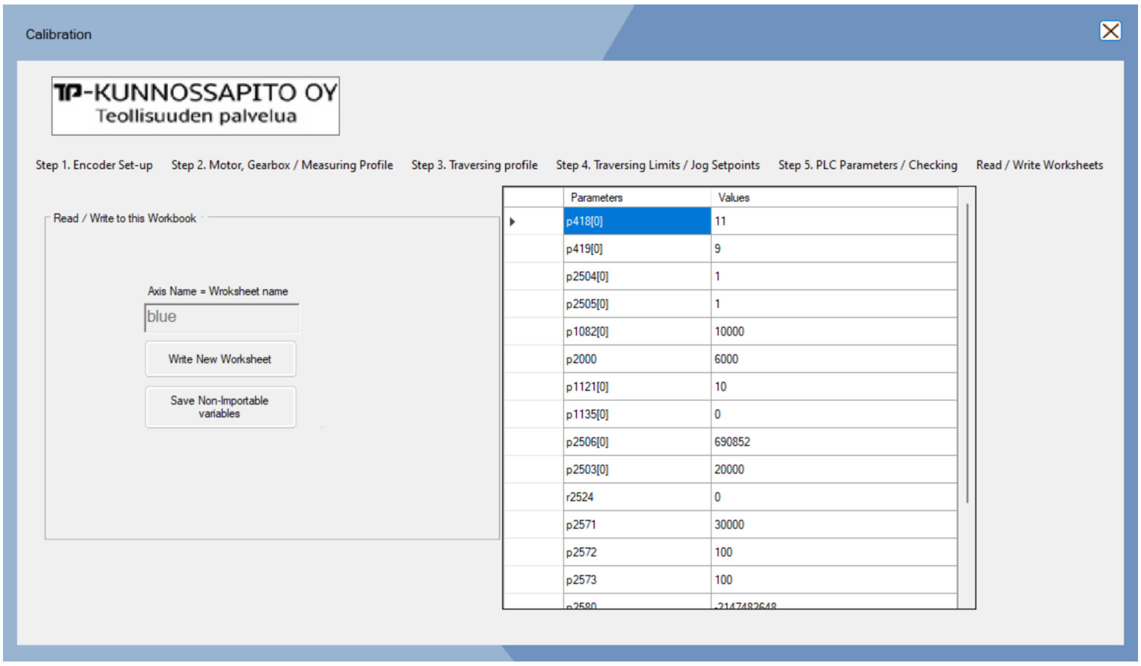

PICTURE 11: Screenshot of the “Traversing limits / Jog Setpoints” page of the calculation interface.




PICTURE 12: Screenshot of the “PLC Parameters / Checking” page of the calculation interface.

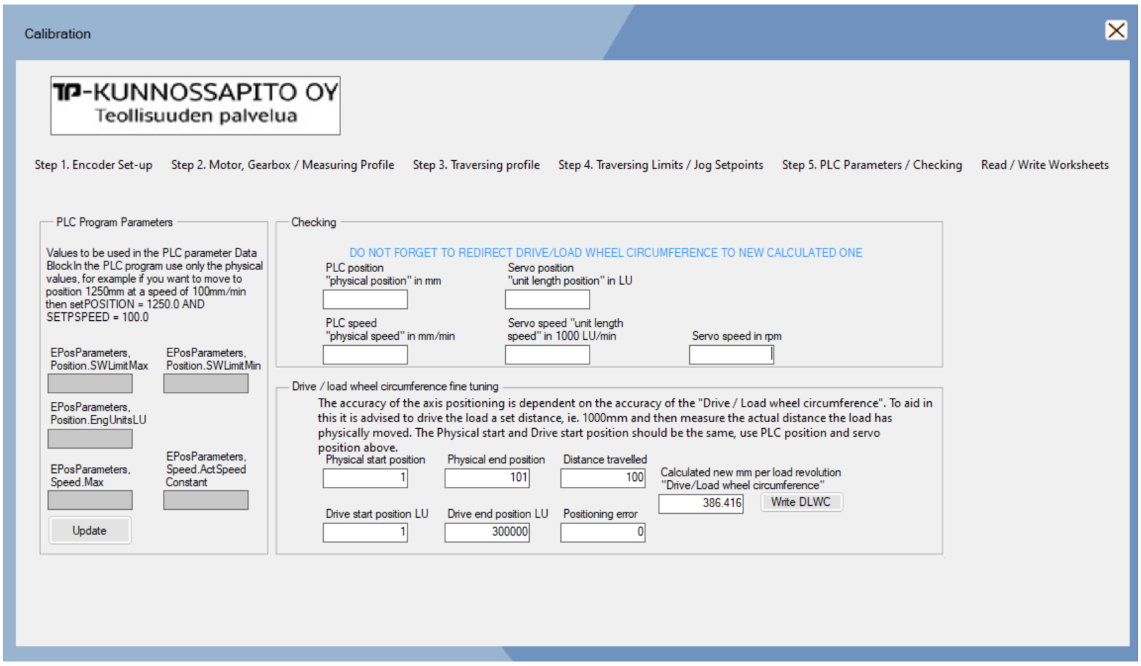
On page 6 of the calculation interface, the user may press the “Save Non-Importable variables” button, which will save the values manually inputted by the user making it easier to calculate the same project drive load wheel circumference in the future further automating the process. Pressing the “Write

New Worksheet” button the user will tell the program to write the new manually changed values including the new drive load wheel circumference into the original TIA Portal project (Picture 13).



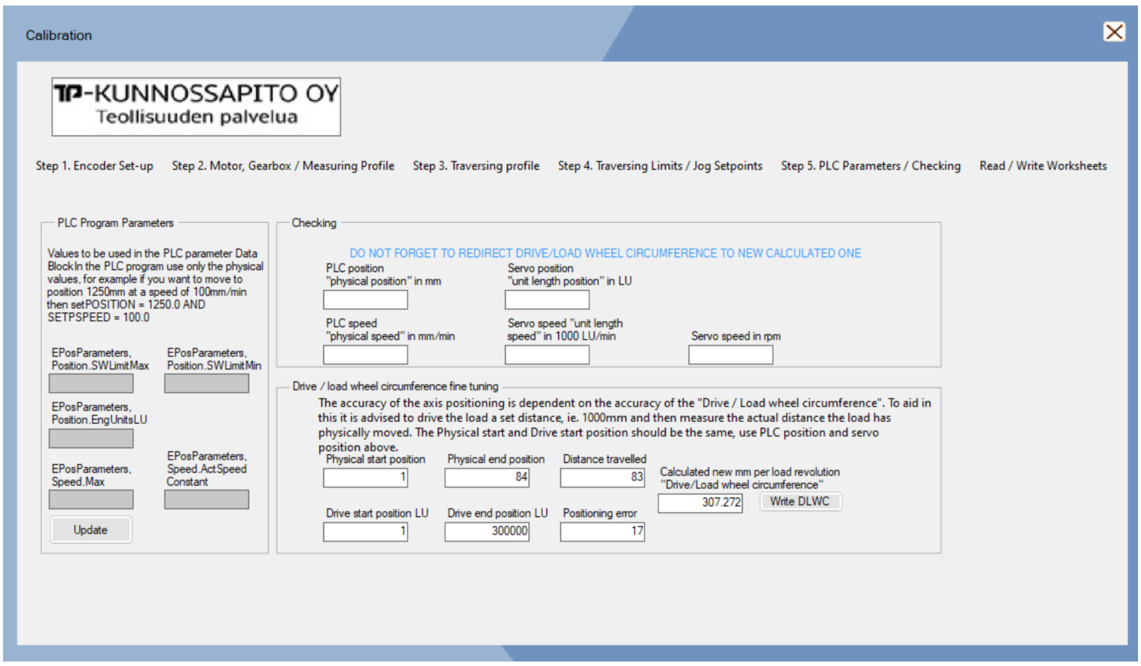

PICTURE 13: Screenshot of the “Read / Write Worksheets” page of the calculation interface.

The next step would be to perform the calculation itself. After manually inputting all the programmatically inaccessible data, the user would then try to control the robot by telling it to move a certain amount (in this example 100 measuring units), measure the result of the movement, and then input the input and real measurements in the page 5 of the program. The example below demonstrates how it looks if the drive load wheel circumference was correct from the start (Picture 14).




PICTURE 14: Screenshot of the “PLC Parameters / Checking” page of the calculation interface with the calculation finished.

However, if the real measurements do not match the inputs, the program will then calculate the corrected circumference, upon pressing the DLWC (drive load wheel circumference) button the program will write the new value in place of the old one (Note: it is recommended to repeat this process several times for the most accurate calculation). The example below shows how it would look if the real measurements did not match the input (Picture 15).



PICTURE 15: Screenshot of the “PLC Parameters / Checking” page of the calculation interface with the calculation in progress.

### 3.2.2 Projects intended effect

The intended use and effect of the project from the point of view of employees responsible for automation, as mentioned previously, was to automate the drive load wheel diameter calculation process in TIA Portal PLC projects. The desired effect of said automation was a decrease in time required to perform said calculation by removing the tedious manual copying of needed parameters, and calculations and writing the new parameters back to the project.

The effect on the company as a whole was foreseen to be a slight overall increase in efficiency of the automation department, as by cutting out the tedious and repetitive part of the drive load wheel circumference calculation, more time could be instead spent working on other projects.

# 4 THE DEVELOPMENT JOURNEY

The following section is presented in the form of a case study documenting the author’s experience learning and later developing the drive load wheel circumference calculation software. The development was split into the learning phase and the execution phase, while both learning and execution phases were themselves split into several stages.

## 4.1 The learning phase

The author started this project only 6 months after starting to study and practice programming, therefore there was still a lot that needed to be learned before beginning to work on the project. The first month of the internship at TP-Kunnossapito Oy was spent learning about complex calculations in C#, transitioning from “looping” console coding to “action/reaction” based coding, and most importantly object-oriented programming and the use of classes in place of repeating code.

Learning and transitioning to object-oriented programming was done by utilising Microsoft’s learning platform Microsoft Learn, as well as completing practical exercises as mentioned previously. Particularly helpful was the Microsoft Learn article on object-oriented programming in C#. This article provides plenty of examples and enough information to be able to start practicing object-oriented programming with practical exercises. (Microsoft Learn 2023.)

### 4.1.1 Bringing programming skills to the appropriate level

This step involved the author developing various programs to learn key concepts for this project. Among these, were developing a scientific calculator to learn complex calculations in C# and a diary app to learn different ways of storing data as memory of the application The final learning project was a drive load wheel calculator to combine the author’s newly learned abilities and transition to object-oriented programming and start using classes. Since the drive load wheel circumference calculator is complex, programming it without the use of object-oriented programming would be very tedious and time-consuming which pushed the author towards the use of classes, finalizing the learning process.

### 4.1.2 Learning the basics of automation programming and engineering

The next step after bringing up the author’s programming skills to the appropriate level was to understand the process that the automation professionals go through when calculating the drive load wheel diameter and the overall PLC programming process in the TIA Portal. Thus began the author's period of learning how TIA Portal works from project creation to PLC simulations.

The learning process consisted mostly of following online tutorials, which there are not many, as it is software used only in a specialized field of engineering, making learning more difficult. The author, however, was lucky enough to get help from the engineering professionals in the Internship/Thesis company, allowing for an overall smooth learning experience.

### 4.1.3 Understanding the TIA Openness API

TIA Portal Openness API is an API made for accessing, editing, creating, and deleting TIA Portal projects, variables, and schematics within. TIA Portal Openness API V16 was used for this project since that is the version that is used by the contractor company.

In order to understand the truly vast functionality of this API the author needed to familiarize themselves with the TIA Portal Openness API V16 manual (Siemens 2021), said manual being 1292 pages long made the familiarization a considerably lengthy process. The author’s approach to this manual was as follows:

First pass through the entire manual marking the sections that could have relevance to this project (sections pertaining to parameter reading, writing, and editing, project creation, saving, editing, and deletion, and use of project and object templates were of most interest initially).
Then carefully read through all the previously marked sections.
After that experiment with code examples and other information given in said sections, which was made easier with the help of available demo applications available on the official Siemens SIE Portal website (Siemens 2023). Finally, experiment with utilizing the information acquired from the manual for the creation of the “Demo” version of the project.

### 4.2 The planning phase

The planning phase commenced simultaneously with the familiarization phase since it only made sense to plan according to newly acquired information. The planning was therefore mostly complete by the point of the completion of the “Demo” or “Proof of concept” version of the project. The plan therefore looked as follows:

1st. Make a proof of concept version showing the possibility of acquiring and editing data from the TIA Portal projects with the use of the TIA Openness API.

2nd. The plan of the approximate final look of the application was to be agreed upon.

3rd. Attachment and integration of two separate parts, those being the calculation interface and the TIA Portal Openness API utilizing interface, were to be achieved.

4th. Finalizing of the application.

5th. Presentation to the contractor.

6th. Receiving the feedback and editing of the project according to said feedback.

### 4.2.1 Understanding the assignment

As the planning of the project was taking place it was important to understand what the project entailed and the specifics of the assignment. Most of the information required for understanding the assignment came from the hiring company contact person, and the rest of the details came from the TIA Openness API manual and understanding of the API’s limits.

As for the information given by the contact person, it was more than enough to formulate the idea of what the project should look like by the end and to make a sketch of the required steps to achieve that as stated above. Whenever problems with understanding arose the author simply contacted the contact person to clarify, which made the planning and working process go smoothly. However, as for the manual and practical learning parts, there were many hiccups, due to the discrepancy in what was initially envisioned and the limitations of the API. More on the matter can be found below in the “The execution stage” and the “TIA Openness API part of the project” parts of this segment.

### 4.2.2 Splitting the assignment into segments

As was previously mentioned in the project plan there were already ideas for the segmentation of the project for reasons of ease of editing, concentration, and debugging, if the project is in segments then there is no question as to where any possible bugs originate. The project was decided to be split into four parts.

First being - the calculation part, which is responsible only for calculating the new drive load wheel circumference, when given all the required parameters to do so.

Second being - the TIA Openness API part, which is responsible only for communication between the author’s project and the TIA Portal.

Third being - the design of the application, which was to be approved by the hiring company contact person.

And the last, significantly smallest, yet essential part being - the communication channel for the calculation and TIA Openness API interfaces.

## 4.3 The execution stage

After establishing the project plan and separating the project into separate manageable chunks, it was finally time to begin the development process itself. As stated above, the calculation part was partially complete as a part of the initial learning process. Therefore the execution stage started with developing the TIA Portal API interface part of the application.

During the execution stage, the author fluctuated between developing the TIA Portal API interface segment of the project and refining the existing calculation segment. The reason for that is that in the field of programming, there happens to be a phenomenon similar to “tunnel vision” when concentrating on a single problem for prolonged periods. Therefore splitting the project into segments resulted in unexpected benefits throughout the development process.

### 4.3.1 Calculational part of the project

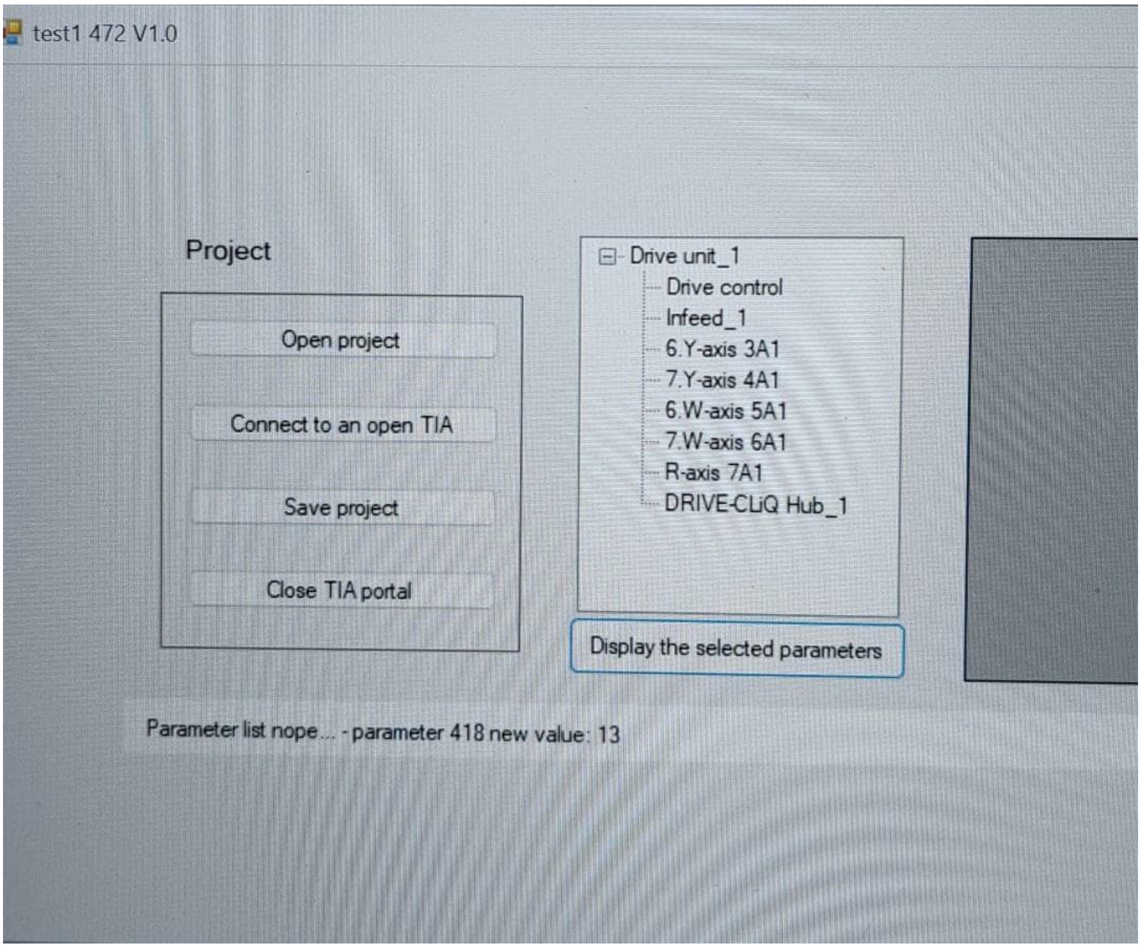
As stated multiple times previously the calculation segment was partially concluded as a training exercise in the portion of the internship that was focused on bringing the author’s programming skills up to the required level. After that, the focus shifted to the API part of the project and remained away from the calculation interface until the author’s exchange to Berlin.

During the exchange, the author managed to successfully merge two incomplete parts of the project, which highlighted what needed to be adjusted in the calculation segment. Among the parts that needed adjustment was the choosing of the encoder type, which was initially done in the calculation interface, yet if there was to be a default encoder type upon the opening of the calculation interface, values could be lost as the encoder type gets changed. Therefore the choosing of the encoder type was moved to happen right before the opening of the calculation interface as a pop-up screen asks for the encoder type or encoder types in case of 2 encoders. Additional features that needed tweaking included the way how the application stores and retrieves memory, calculation optimization, and overall finalization of the visual aspects of the interface.

### 4.3.2 TIA Openness API part of the project

As stated before, the part of the project responsible for communicating with the TIA Portal using the TIA Openness API became the main focus the moment when the author’s programming skills and knowledge of the API became sufficient. The development of said project segment proved to be significantly more challenging as well as time-consuming than any other portion of the entire project.

The development of the interface which would later be responsible for communicating with the TIA Portal, began with creating a sort of demo visuals, which entailed deciding how any buttons of what kind are needed and how the layout is going to look (Picture 16).




PICTURE 16: Photo of the early look of the application. Note: in this photo, the parameter list is already replaced with the project browser.

The final version of the application was sure to differ significantly from this early “sketch”, however, it was a starting point from which the author could begin experimenting with ways to access TIA Portal projects and manipulate parameters within.

After creating the visuals came a long and difficult process of experimentation with the TIA Openness API capabilities and limitations, which resulted in several pivots and deviations from the original functionality of the application. Among significant changes from the core concept was for example the decision to exclude the intended “preset project” creation capabilities, due to the amount of time that would be saved from excluding said functionality. Additionally, the application memory which was initially not accounted for, demanded implementation, since the initial idea of reading all the required parameters from the TIA Portal project itself was found to be not implementable. The reason for the inability to implement said feature is simply a limitation in and of the TIA Openness API and is avoided by simply introducing the application memory that would only require the user to input the unreachable values once, thereafter they would be read from memory when accessing the same project.

### 4.3.3 The pause and return to the project

The project development however came to a prolonged pause, as the author was to travel for exchange studies to Berlin, Germany for 6 months, in part to improve their programming skills and acquire new programming insight. During the exchange, the author focused on developing the visual design of the application to satisfy the requirements of the contracting company. In addition to that the author began work on melding the incomplete sections of the project as at that point there was enough working content to make the first working “Demo” versions of the project.

Following the author's return to Finland, the internship at TP-Kunnossapito Oy was resumed. The following months were spent polishing and perfecting the project based on feedback given by the contractor. The author would like to note a noticeable improvement in their programming skills as well as the replenished vigor, which led to a hasty finalizing of the project.

## 4.4 The follow-up stage

Nearing the end of the second internship at TP-Kunnossapito Oy the author began showing the program to the contact person at TP-Kunnoissapito Oy, as the contact person for this thesis was the person who ordered the application in the first place and was the intended user. This showing of the application was done to collect feedback and implement changes tailored to the needs of the intended user, this resulted in plenty of final adjustments.

### 4.4.1 Collecting feedback and implementing adjustments

During the process of collecting feedback and implementing adjustments based on said feedback, many changes were implemented into the project. These changes ranged from visual adjustments to entire features being changed or removed entirely. The decision to remove the ability to create and delete projects, for example, was made during one of such feedback sessions.

Among other notable changes to the project were:

The decision to move the property list to the calculation interface since initially it was shown right after the selection of the project on the communication interface.

The decision to replace the now moved property list with the project explorer.
The decision to implement the encoder selection interface before the calculation phase of using the application.

The extent to which the author was able to achieve feedback and cooperation from the contractor and final user allowed for the unique opportunity to tailor the final experience to an extreme degree. The actual use of the final product is yet to commence as it was intended to be used approximately during the summer, and after the field testing additional updates and bug fixes are expected to be required.

### 4.4.2 Upkeep and updates

The author expects bugs to be discovered in the field since the application could only be tested with the help of the server that was generously provided by Siemens, and though it seemed to run well on the server, it may not well represent the final user experience. Bugs are an unavoidable side to programming, and unless a programmer utilises pre-written and tested code, there is an almost unavoidable possibility of encountering bugs, thus resulting in the need for patches.

Additional reasons for the need for continuous updates and patches are mainly the new versions of TIA Portal that may be used by the company at a later date, and overall changes in practices, or possible additions to the desired functionality. At the current point in time, the company utilises TIA Portal v16, however, that is expected to change sooner or later since currently, v19 is already available.

# 5 DISCUSSION

The objective of this thesis was to detail the development of a drive load wheel circumference calculation software that would automate the existing process of said calculation. The purpose of this thesis was to create and implement the drive load wheel circumference calculation software that uses the TIA Openness API, using both business and programming knowledge gained during the author's studies. The second purpose of this thesis was to outline the importance of automation in the current times, as well as in the recent past, and to outline the recent developments in the field of warehouse management automation. The thesis outcome is in the form of an overview of the path the author took in developing the drive load wheel circumference calculation software as well as the application usage guide that could potentially be used as a user manual for the employees in the contracting company.

The first and most important result of this thesis is practical, and that is the drive load wheel circumference calculation application that was commissioned by TP-Kunnossapito Oy. The application consists of several interfaces, one responsible for communicating with the TIA Portal projects using the TIA Openness API, another responsible for the calculations based on the parameters retrieved from the project, and other interfaces responsible for project and encoder selection. The second result of this thesis is theoretical, and it is an overview of the user experience when properly using the application, which consists of written instructions as well as screenshots of the visual part of the experience. Said overview can also serve as an application user manual that shows how to calculate a correct drive load wheel circumference step-by-step, which could be used by future users and employees at TP-Kunnossapito Oy.

The data collection methods for this thesis were mostly of a qualitative nature, utilizing such data collection methods as content analysis where information was gathered from online sources together with literature, and additional information was gathered from the case study. In the practical part of the thesis, the experimental method consisted of experimentation with the capabilities of the TIA Openness API. The primary idea of this experiment case study was to learn from the experience of the calculation application development process, documenting all the steps of said application development.

The case study laying in the center of this thesis implies some ethical rules to be followed when sourcing data, and working with the company that provided the author with the opportunity for this project. When it comes to the customer, the ethical rule was absolute transparency, all steps and all the information included in this thesis were cross-checked with the contact person from the company, in order to allow them full control over any potentially sensitive information. Regarding data sourcing for the theoretical part of the paper, all the data sources were legal and ethical. The data was gathered from official sources, which were all credited appropriately in the format required by Tampere University of Applied Sciences.

When it comes to the author’s experience developing the drive load wheel circumference calculating software, as well as the experience writing this thesis, they left an impact that is sure to have a lasting effect on the author. It is sure to affect any future projects and the overall professional development of the author. The experience of writing this thesis taught the author the history of automation, especially in the warehousing field, and additionally, it strengthened the author’s belief in the importance of automation and gave a concrete knowledge basis for said belief. When it comes to the effects the development project had on the author, can not be overstated. This project gave new perspectives in addition to skyrocketing the author’s programming skills and knowledge. Additionally, it provided the author with a perspective of working in a Finnish company focused on technology, surrounded by industry professionals, it overall gave a taste of potential future working environment to the author.

The limitation of this thesis is the fact that it is very focused on the development of one specific project, which limits the overall reach of the thesis. The focus could be shifted to a wider topic of automation in warehouse management if not for the practical part of the thesis. Additional limitations came with the scale of the application developed as there were factors limiting the development speed and with that limiting the potential scale. Among such factors, there was a need to wait for Siemens to provide a server to the TP-Kunnossapito Oy office for testing the application. Future students could use this thesis as a basis for a wider range research in the warehouse management field and in particular automation with the help of robots.

As for recommendations from the author to the contracting company, there is the potential benefit to be had from eventually implementing the functionality that was initially planned but removed further in the development process. TP-Kunnossapito Oy could benefit from automating the creation of TIA Portal projects from templates, leading to potential time savings. Expectedly there is the recommendation of continuous investment in automating repetitive tasks, however, the company does not seem to plan on slowing down in this regard any time soon, said automating is surely to lead to further increases in productivity and morale of employees.

## REFERENCES


Alexander S. Gillis, 2021. object-oriented programming (OOP). TechTarget. Website. Read on 01 Apr. 2024. https://www.techtarget.com/searchapparchitecture/definition/object-oriented-programming-OOP

JR Automation. 2023. USING AUTOMATION TO IMPROVE WAREHOUSE EFFICIENCY. Blog. Read on 13 Apr. 2024. https://www.jrautomation.com/blog/blog/2023/12/08/using-automation-to-improve-warehouse-efficiency

KPI Solutions. N.d. The Importance of Operational Efficiency in Warehouses: A Closer Look at Equipment. Article. Read on 2 Apr. 2024. https://kpisolutions.com/resources/the-importance-of-operational-efficiency-in-warehouses-a-closer-look-at-equipment/

Kumar, S. 2021. Revisiting the warehouse research through an evolutionary lens: a review from 1990 to 2019. Taylor & Francis Online. Article. Read on 20 Mar. 2024. https://www.tandfonline.com/doi/epdf/10.1080/00207543.2020.1867923?needAccess=true

Microsoft Learn. 2023. Object-Oriented programming (C#). Article. Read on 17 Jan. 2024. https://learn.microsoft.com/en-us/dotnet/csharp/fundamentals/tutorials/oop

Modula. 2023. 15 Types of Warehouse Robotics For Optimal Efficiency. Website. Read on 01 Apr. 2024. https://modula.us/blog/warehouse-robotics/

Musaoglu, E. 2023. Exploring automated warehouse robotics – types, benefits & more. Logiva. Blog. Read on 01 Apr. 2024. https://www.linkedin.com/pulse/exploring-automated-warehouse-robotics-types-benefits-more-logiwa

Partida, D. 2022. How Does Automation Promote Employee Efficiency? Article. eLearning Industry. Read on 11 Apr. 2024. https://elearningindustry.com/how-does-automation-promote-employee-efficiency

Robotnik. 2023. How does mobile robot technology increase warehouse productivity? Blog. Read on 15 Mar. 2024. https://robotnik.eu/how-does-mobile-robot-technology-increase-warehouse-productivity

Siemens. 2017. Startdrive SINAMICS Programming and Operating Manual. System Manual. Online documentation. Read on 29 Jan. 2024.

Siemens. 2021. SIMATIC TIA Portal Openness: API for automation of engineering workflows. System Manual. Online documentation. Read on 24 Jan. 2024.

Siemens. 2021. Tips for TIA Portal Openness. FAQ. Read on 7 Feb. 2024. https://support.industry.siemens.com/cs/document/109251656/tips-for-tia-portal-openness

Siemens. 2023. TIA Portal Openness: Introduction and demo application. Application example. Read on 14 Feb. 2024. https://support.industry.siemens.com/cs/document/108716692/tia-portal-openness-introduction-and-demo-application

Smith, P. 2019. Advantages & Disadvantages of Siemens' TIA Openness. BMC. Article. Read on 01 Apr. 2024. https://www.dmcinfo.com/latest-thinking/blog/id/9877/advantages-disadvantages-of-siemens-tia-openness

Tardi, C. 2023. FIFO vs. LIFO Inventory Valuation. Investopedia. Website. Read on 01 Apr. 2024. https://www.investopedia.com/articles/02/060502.asp.

Universal Robots. 2022. The ultimate guide to palletizing robots. Blog. Read on 14 Mar. 2024. https://www.universal-robots.com/blog/the-ultimate-guide-to-palletizing-robots/

What is TIA Portal from Siemens? 2023. Blog. Automationfair. Read on 01 Apr. 2024. https://www.automation-fair.com/what-is-tia-portal-from-siemens/

Young, L. 2023. Companies Are Slow to Adopt Robot-Operated 'Dark' Warehouses. The Wall Street Journal. Article. Read on 01 Apr. 2024. https://www.wsj.com/articles/companies-are-slow-to-adopt-robot-operated-dark-warehouses-46e1c887

# APPENDICES

Appendix 1. Interview questions

Questions to ask:

What is the nature of the project?

Why do you need the project?

How is the job done currently without the project?

Why is it specifically C# that is needed to complete the project?

What is the programming language the robot code is written in?

Do I need protective equipment?

Where do I start?

What do I need to research in preparation for the project?

what kind of structure is the project communication going to have?

where am I going to be completing the project?