A fully automated asset-tracking RFID system

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Abstract

This project project aims to explore the feasibility of developing an autonomous asset-tracking system that operates without human intervention. Based on this statement, an analysis exploring different technologies is made. Also, tests and different solutions have been explored and a value chain is analysed by using state of art methods. For a better understanding of the current state of the company. In order to choose the right solution, a data driver technology comparison has been made and a study of the challenges that come with each technology. Also, presents a fully functional beta version of the automated tracking system, which serves as a tangible demonstration of the project's progress towards achieving a fully autonomous solution. The implemented system embodies the culmination of the research efforts, showcasing the potential for practical implementation in real-world scenarios.

Keywords: RFID, Asset-tracking,

1. Introduction

In today's fast-paced and dynamic business environment, efficient asset management is crucial for organizations operating in the equipment rental industry. Among these organizations, the assessed company has emerged as a prominent nationwide supplier, providing rental equipment. However, the company faces a significant challenge in accurately tracking its diverse inventory of small and large assets, resulting in difficulties when assigning invoices and managing the movement of assets effectively.

This paper aims to address the aforementioned challenge by investigating the implementation of advanced asset tracking technology within the company's operations. By conducting thorough research and analysis, we seek to develop a comprehensive understanding of the asset tracking needs specific to the company's unique requirements. Subsequently, we will explore potential solutions that leverage cutting-edge tracking technologies to optimize asset management processes, mitigate losses, and enhance overall operational efficiency.

The absence of a reliable and efficient identification system for tracking assets poses significant hurdles for the company. The frequent movement of assets between various locations further complicates the task of determining the precise whereabouts of lost or misplaced assets. Consequently, this issue not only leads to financial implications for the company but also hampers customer satisfaction, as accurate invoicing and timely asset availability become challenging.

To overcome these challenges, our research will focus on investigating various asset tracking technologies, including but not limited to Radio Frequency Identification (RFID), Global Positioning System (GPS), and Internet of Things (IoT) solutions and others. By analyzing the benefits, limitations, and implementation requirements of each technology, we aim to identify the most suitable asset tracking solution that aligns with the company's operational needs, scalability, and budgetary constraints.

Moreover, this research will delve into the integration of asset tracking systems with the company's existing processes, exploring potential synergies and streamlining procedures. We will evaluate the potential impact of implementing asset tracking technology on the overall efficiency, accuracy, and profitability of the company's operations. Additionally, considerations regarding data security, privacy, and maintenance requirements will be addressed to ensure a comprehensive and sustainable solution.

2. State of art technologies

Various technologies play a crucial role in tracking and identification systems. Radio Frequency Identification (RFID) utilizes tags with an electronics chip and antenna to store and transmit data, enabling unique identification of objects or individuals. Bluetooth Low Energy (BLE) offers low-power consumption and proximity detection, making it useful for asset tracking. Ultrawide Band (UWB) technology provides high-precision location determination through precise time-of-flight measurement. The Global Positioning System (GPS) enables accurate positioning and navigation globally. Wi-Fi networks, [1] with methods like received signal strength-based fingerprinting, contribute to location tracking. Long-Range Wide Area Network (LoRaWAN) [2] operates on a license-free radio band for long-range communication and data transfer. Additionally, Long-Term Evolution (LTE) [3] and computer vision systems, utilizing image analysis and AI algorithms, aid in asset tracking and logistics optimization. These technologies have revolutionized tracking, identification, and supply chain management in various industries.[4]

All these technologies and their specs can be seen in comparison with each other in Figure 1.

TYPES	RFID		BLE	UWB	WI-FI	LORAWAN	LTE+GPS	COMPUTER VISION
CRITERION	PASSIVE	ACTIVE						
COMPANIES PROVIDERS	Zebra, Alien, GlobeRanger, OrbComm, Impin	Zebra, Alien, OrbComm, Airfinder	Quuppa, Confidex Viking, Aruba, Bastian, Airfinder	Pozyx, Decawave, Kinexon, Alereon, Humatics, Zebra,	Aruba, AeroScout, Ekahau, Redpine Signal, CalAmp	Lora Alliance, Semtech	Lora Alliance, Semtech	Sibrtech
OPERATION	Identification	Identification	Identification + Possitioning + Sensor	Identification + Possitioning + Sensor	Identification + WPS + GPS	Identification + WPS	Identification + GPS	Identification
SUITABLE FOR	Spot detection	Spot detection	Area detection	Area detection	Area detection	Area detection	Area detection	Area detection
RANGE	<1 m	<1 m	5 - 50 m per reader	20-100m per station	< 150 m	>10000 m	unlimited	Based on possible interference
ACCURACY	< 10 cm	< 10 cm	2 - 3m , <8 m	< 30 cm	<15 m	>500 m	<10m	Based on resolution
BATTERY	No battery	3-5 years	2 - 5 years	< 2 years	-	-	-	Based on resolution 1080p 60fps: 120 minutes
TAG COST	0.5 dkk	130 - 750 dkk	750 dkk	750 dkk	750 dkk	750 dkk	750 dkk	Expensive
POWER CONSUMPTION	Low	Medium	Medium	High	medium	High	High	High

Fig. 1 Specification per technology.

3. Methodology

Within the context of organizational operations, the paramount concern revolves around maximizing value. Contemporary management theories emphasize the significance of discerning the precise sources of value within operations, as this knowledge provides invaluable insights. Analyzing the value chain assumes critical importance, enabling a comprehensive understanding of the key areas that warrant focused attention. By delving into the intricacies of the value chain, organizations can strategically prioritize and optimize their operations for enhanced performance and competitive advantage.

3.1 Value stream

The value stream is a pivotal methodology that centers on the analysis of value-adding processes within a company or organization, with a particular emphasis on departmental interfaces and collaboration among colleagues. As a company operates, it engages in numerous procedures required to accomplish projects. These projects entail a combination of value-adding processes and non-value-adding processes, both of which have a direct impact on the final product or service delivered. By employing this tool, organizations can gain a comprehensive overview of their entire operations and discern any non-value-adding processes that exist within the value stream. This critical analysis enables targeted improvements and optimizations to enhance overall efficiency and ultimately deliver superior value to customers.[5]

To be able to understand all these information easily and quickly, value stream mapping is a tool that can visualize all these processes in a single diagram with all the relevant information visible as can be seen in Figure 2. This way of mapping information has many benefits according to [6]:

- Including serving as a focal point for team meetings.
- Illuminating techniques for safe and efficient working procedures.
- Explaining to everyone how performance is assessed.
- Analyze the operation's condition at a glance.
- Comprehend the tasks and work priorities.
- Evaluate your performance and that of others.
- Determine the flow of work - what has been done and is being done.
- Recognize when things is not going according to plan.
- Demonstrate the agreed-upon standards.
- Reduce the dependency on formal meetings by giving everyone involved real-time performance feedback.

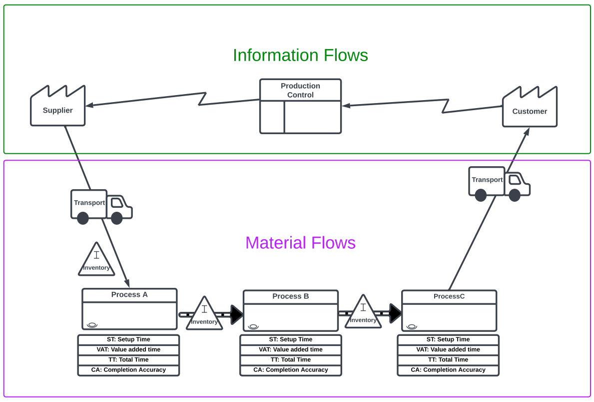

Fig. 2 Generic template of value stream mapping.

During the data collection phase for the development of a value stream mapping, three primary sources of data need to be considered. Firstly, there is the resource data, which holds particular relevance in cases involving a production line. This data entails quantifying the total number of completed items within each process step, referred to as Batch Size (BS), as well as the number of personnel required to carry out the respective process step, denoted as People (PP).

The second source of data, applicable to any scenario under evaluation, is Time-Based Data. This category encompasses various time-related measurements. For instance, Set up Time (ST) represents the duration required for equipment preparation before commencing a process step. Change Over Time (CT) denotes the time needed to transition the equipment between different production runs. Value Added Time (VAT) signifies the time taken for a single unit to be completed, while Total Time (TT) represents the overall duration for completing a batch. It is important to note that these terms encompass a broader scope beyond just manufacturing, extending to services as well.

Lastly, the third source of data is Quality-Based Data, which encompasses Completion Accuracy (CA). This metric reflects the precision with which items are completed on the first attempt or trial.

3.2 Gap Analysis and Problem Mapping

In order to effectively identify and address operational issues, the utilization of gap analysis and problem mapping techniques proves indispensable. These tools facilitate the systematic identification and differentiation of problems within an organization's operations, while also delving into the underlying causes of these issues. By employing these analytical approaches, organizations can gain a comprehensive understanding of the problems at hand, enabling them to propose solutions based on precise and accurate information. This proactive problem-solving approach ensures that interventions and remedies are targeted and effective, leading to improved operational performance and enhanced outcomes.

3.2.1 Gap analysis

Gap analysis is an influential instrument employed to evaluate the performance of an organization, with the primary objective of assessing the extent to which operational goals are being achieved. By meticulously examining the variance between desired objectives and the current performance levels, this analytical tool effectively measures the "gap" that exists. The magnitude of this gap provides critical insights into the areas that require attention and improvement. [7]

Through the systematic application of gap analysis, organizations gain a comprehensive understanding of the deviations from desired outcomes, enabling them to identify specific actions and initiatives necessary to bridge the identified gaps. This rigorous assessment facilitates the formulation of targeted strategies and interventions, ensuring that resources and efforts are channeled effectively to close the performance gaps and optimize overall operational performance.

Upon completion of the value stream mapping, a comprehensive assessment of operational activities is obtained, enabling the identification of value-adding and non-value-adding areas. Drawing insights from these areas and considering other relevant factors, organizations can establish strategic goals. Subsequently, a thorough analysis of the current state of the company is conducted, leveraging the findings from the value stream mapping and aligning them with the established goals. This analysis allows for the quantification of the "gap" that exists between the current state and the desired state.

Based on this measured "gap," a range of recommendations can be proposed. In some cases, further in-depth analysis may be warranted, as depicted in Figure 3. To address complex issues that require a breakdown and detailed examination, specialized tools such as Problem Mapping can be utilized. By employing such tools, organizations can effectively navigate and resolve multifaceted challenges, fostering informed decision-making and driving continuous improvement within their operations.

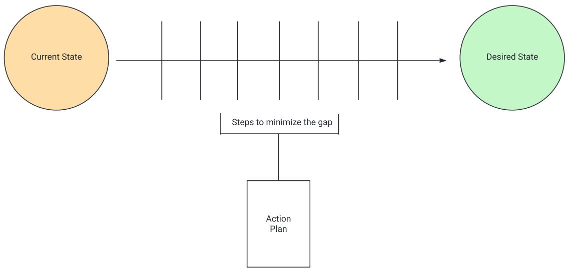

Fig. 3 An example of gap analysis.[7]

3.2.2 Problem mapping

Problem Mapping provides a structured approach to dissect and analyze intricate problems, enabling a comprehensive understanding of their underlying causes and potential solutions. Also it serves as a valuable visualization tool designed to facilitate the identification and in-depth analysis of potential causes underlying a problem. By visualizing and analyzing the problem at hand, organizations can effectively uncover the root causes, thereby enabling targeted actions and the exploration of viable solutions. The application of problem mapping involves a systematic four-step approach, as outlined by [8], to ensure a comprehensive problem analysis.

1) Brainstorm primary causes and concepts.
2) Brainstorm second-order causes.
3) Add interrelationships between causes.
4) Define causality of each relationship.

An effective approach to visually represent the relationship between problems and their causes is through the utilization of nodes. Through a collaborative brainstorming process, all primary and secondary causes of the problem are identified, and further exploration may extend to higher levels such as third, fourth, and beyond. By organizing these causes as nodes, it becomes possible to establish interrelationships and define their causality, denoted by positive and negative influences.

In Figure 4, a generic example is provided, illustrating this node-based representation of the problem and its causes. This visual representation offers a concise and structured means to comprehend the complex web of cause-and-effect relationships.

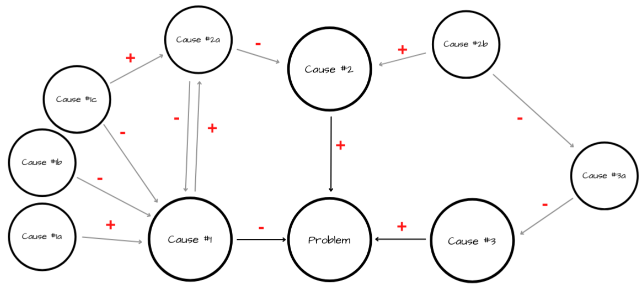

Fig. 4 An example of problem mapping. [8]

By employing this professional approach, organizations can effectively map out and analyze the intricate network of causes associated with a problem, gaining valuable insights into its underlying dynamics. This methodology fosters a comprehensive understanding of the problem landscape, enabling informed decision-making and facilitating the formulation of targeted solutions.

3.3 Digital Maturity

Digital maturity refers to an organization's ability to effectively utilize digital technologies and leverage them for business success. It encompasses both digital capabilities, such as processes and strategies, and leadership capabilities, such as management and culture. It involves the organization's readiness to respond to market opportunities by integrating technology, people, and processes for achieving desired business outcomes.

The tool that is used was developed by [9] from Aalborg University developed a maturity assessment model based on Problem Based Learning (PBL) called 360 Digital Maturity Assessment (360DMA). They evaluated the results using a different scaling in this method. They suggested six steps for assessing the degree of digitalization.

1) None: No digitalisation is taking effect within the organisation.
2) Basic: Within the company, some digital data are created (usually locally on PCs or workstations).
3) Transparent: Within the organization, data are generated and shared for operational purposes only.
4) Aware: Data are being managed and analysed for business insights and performance indexes.
5) Autonomous: Data are available and fully functional in a form that allows for real-time decision-making.

6) Integrated: Within the entirety of the organization, data are processed automatically, along with decision-making.

The steps outlined bear resemblance to the model employed by Acatech [10], which, based on their extensive bibliographic research, emerged as the sole model adaptable to accommodate diverse data sources required for the evaluation process. This adaptability allows for a more nuanced assessment of the current state of the organization. The data collection phase incorporates a combination of structured questionnaires and site visits, enabling comprehensive data gathering.

So, [9] modified Acatech's and expanded the evaluation instrument to encompass five essential digital dimensions, which serve as key indicators to assess the organization's present state:

- Governance: The organizational structure, tactics, and resources, among other things.
- Technology: Assets and machinery associated to digital data.
- Connectivity: Infrastructures and methods for moving data both inside and outside of the organization.
- Value Creation: Instruments for data analysis and value creation (Automated planning etc.)
- Competence: Tools, abilities, and mindset in the process of digital transformation.

In order to evaluate the digital maturity within an organization, this tool, according to [9], comprises five steps that are based on the PBL. First, a team of professionals who will communicate with the organization must be assembled for the assessment. This helps the business have a better grasp of the process and produces better results as a result. The purpose of this tool is to facilitate communication between the company and the evaluation party.

Creation of awareness: In this step, the assessment team envisions the ideal scenario aligned with the company's vision, gaining insights into its digital transformation potential through technologies, concepts, and information about its practices, objectives, and more. This shapes the backdrop of the digital maturity assessment.

Definition of Scope: In the second stage, the focus is on clarifying the problem being investigated. The organization shares its strategy, goals, and development perspectives to identify key areas that are crucial for the assessment. Through open conversation, the scope of the assessment process is defined.

Data Collection: Data gathering is essential to evaluate the identified scope. This involves conducting open discussions with the company's management or relevant individuals from each department to gather crucial information. Questionnaires may also be employed to gain further insights for the assessment.

Evaluation and solution selection: Once data and information are collected, the entire team evaluates them. The information is categorized and mapped based on the dimensions of the digital maturity model. The maturity stage of each dimension is determined, highlighting key gaps and differences among them. Improvement proposals are then generated to enhance digital maturity and address the identified gaps and scope-related issues.

Debriefing: The final step involves presenting assessment findings to firm representatives, including in-depth presentations on the identified "key gaps" and recommendations. Recommendations can be provided as short, medium, and long-term improvements, utilizing visual aids like spider graphs to enhance understanding.

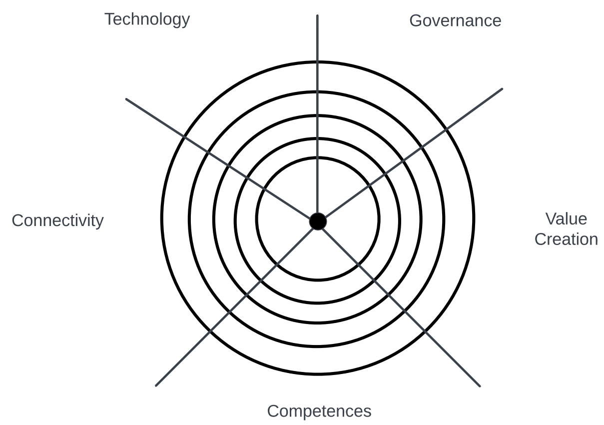

Fig. 5 Spider Graph for Digital Maturity Dimensions according to 360DMA. [9]

4. Concept Development

The value stream mapping and insights from the company's interview highlighted the need to reduce time spent on equipment handling, indicating the need for a Gap analysis. By comparing the current state to the desired goal, the analysis identified a gap in counting and checking operations. This analysis helped investigate underlying causes and generate potential solutions. The next step is to analyze the problem of missing items and address root causes. Also, in the digital maturity assessment, two out of five dimensions were low which concluded in actions such us suggestions which would increase these dimensions.

All of these concluded in the final problem formulation:

"Design and develop a robust and in-dependable tracking system, capable of autonomously monitoring a significant quantity of assets, while ensuring its resilience in diverse environmental conditions, albeit with a potential consideration for cost-effectiveness"

This section aims to provide a comprehensive assessment of various technologies based on individual requirements. Each technology has been assigned a rating on a scale of zero to ten, tailored to meet specific criteria. These criteria are categorized into three sections: "must have," "should have," and "could have." The "must have" section carries a multiplier of three, indicating its critical importance, while the "should have" section has a multiplier of two, and the "could have" section has a multiplier of one. Consequently, the assigned ratings for each requirement are multiplied by their respective multipliers and summed together to determine the overall score for each technology. A higher overall score denotes a more favourable evaluation.

		RFID									
REQUIREMENTS		125KHZ	13.56MHZ	UHF	ACTIVE	BLE	UWB	WI-FI	LORAWAN	LTE+GPS	COMPUTER VISION
Must Have *3 points	Automated Asset Counting for Truck Drivers	10	10	8	8	10	10	10	10	10	4
	Friendly for Untrained Volunteers	10	10	10	10	10	10	10	10	10	8
	Low Interference in Metalic Enviroment	8	6	5	5	10	8	8	8	8	10
	Low Interference in Rainy Conditions	10	9	6	6	10	10	10	10	10	10
	Compatibility with Equipment and Transportation Infrastructure	8	8	10	10	10	10	10	10	10	10
	Ease of Implementation on Existing Assets	7	7	10	10	10	10	10	10	10	10
	User-Friendly Interface for Headquarters Personnel	10	10	10	10	10	10	10	10	10	10
	Low Cost Implementation	10	9	8	5	2	1	1	1	1	1
	Monitoring the Process of Asset in Loading and Unloading	10	10	2	8	10	10	10	10	10	5
	Individual ID's for each asset	10	10	10	10	10	10	10	10	10	1
	Scalable	10	9	7	3	3	2	2	2	2	3
Could Have *2 points	Adaptability for Different Asset Types	8	8	10	10	10	10	10	10	10	3
	Long Life Time	10	10	10	5	5	5	5	5	5	5
	Errorless tracking	7	7	7	8	9	9	9	9	9	4
	Fully Automated	10	10	10	10	10	10	10	10	10	10
Could Have *1 point	Wireless Connectivity	2	2	5	7	8	10	10	10	10	-
	Tracking the truck of delivery with all the assets	1	1	1	1	1	10	10	10	10	-
	Location Data	-	-	2	2	5	10	10	10	10	-
	Time Data	10	10	10	10	10	10	10	10	10	10
	Usefull Metadata	7	7	7	7	8	8	9	9	10	5
	Tracking in festival	-	-	2	3	5	5	7	8	10	-
	No Battery or Long Battery Life	10	10	10	5	5	5	3	3	2	-
	Total	409	394	369	356	395	399	400	401	403	275

Fig. 6 State of art comparison in regards to the requirements.

5. Proof of Concept

During the equipment selection process to align with the specified requirements, a comprehensive market analysis was conducted. Following the evaluation, it was determined that the most suitable option available within a constrained timeframe was the M5Stack solution. M5Stack is a renowned company that offers an ecosystem centered around the ESP32 processor and Arduino-compatible solutions.

To evaluate and compare these two frequency options in commercial products, a diverse range of RFID-enabled devices were scrutinized, ensuring a comprehensive assessment of their respective capabilities and performance characteristics. A full list of the equipment available for tested can be seen below:

Tab. I Equipment that was tested according to the requirements for proof of concept.

RFID Related	
PN5180	13.56 MHz contactless NFC
PN532	13.56 MHz contactless NFC
MFRC522	13.56 MHz contactless NFC
WS1850S	13.56 MHz contactless NFC
RDM6300	125 kHz contactless NFC
113020002	125 kHz contactless NFC
RFID Tag	13.56 MHz NFC
RFID Tag	125 kHz NFC
Other related equipment	
GPS Module	AT6558
Battery	700 mAh
LTE Module	SIM7600G
SD Card	NT02P500STN-032G-R
Microprosessor	
Core Kit V2.6	240MHz dual core, 520KB SRAM

For programming it was mainly was developed primarily in Blocky by Google with minor modifications in microPython. The primary objective of this code is to display comprehensive information on the microprocessor's LCD while concurrently transmitting relevant data to a designated server through the utilization of an API. The server-side API code responsible for processing transmitted data was in next.js. This architecture was to ensure reliable and convenient data transmission, storage, and retrieval across multiple devices.

Furthermore, a dedicated application webpage was developed to enhance data visualization and provide a user-friendly environment for viewing server logs and transmitted data. This real-time update interface offers an improved user experience, facilitating efficient data monitoring and analysis.

In the final phase of the proof-of-concept stage, a program was developed to extract and process the data for real-time asset tracking. The code is suitable for producing the data into the company's existing system. By executing this program, relevant data could be efficiently retrieved and made accessible to both the internal system and human users. The program also included features such as searching for RFID IDs, identifying missing IDs, exporting data in various formats, and displaying asset locations on an interactive map. This map-based visualization enhances situational awareness and facilitates efficient decision-making based on real-time asset positioning information.

5.1 Testing

After assembling and programming all the available equipment, the next step was to reassure that all the requirements in section 4 are meet. For this purpose a series of testing needed to be done in several scenarios that simulates the real case.

The initial step involved rigorous testing of the equipment under optimal conditions, referred to as "normal conditions." These ideal conditions were characterized by an unobstructed environment where there were no materials present between the RFID sensor and the tag. The testing process encompassed evaluating the equipment's performance at various distances, aiming to determine the maximum operational range and assess its usability under different proximity scenarios.

This systematic approach provided valuable insights into the equipment's capabilities in optimal conditions, enabling a comprehensive understanding of its functionality and performance. The data collected from these tests served as a foundation for further analysis and informed decision-making in subsequent stages of the project.

As anticipated, the experimental results presented in Table Table II align closely with both the theoretical model derived from the equipment specifications and the prevailing knowledge in the field of RFID technology. These findings affirm the accuracy and reliability of our equipment, validating its performance against the expected outcomes.

The consistency between the empirical data and the theoretical model underscores the meticulous design and calibration of the RFID equipment. Moreover, it reinforces our confidence in the equipment's ability to operate within the anticipated range and deliver precise and reliable results. The confirmation of our equipment's performance under normal conditions serves as a strong foundation for further exploration and validation in more challenging environments.

Tab. II Testing of RFID in Normal conditions.

	Experiments			
	1 cm	2 cm	3 cm	4 cm
PN5180	Passed	Passed	Passed	Failed
PN532	Passed	Passed	Passed	Failed
MFRC522	Passed	Passed	Passed	Failed
WS1850S	Passed	Passed	Passed	Failed
RDM6300	Passed	Passed	Passed	Passed
113020002	Passed	Passed	Passed	Passed

During the concept development phase, a protective casing was designed to accommodate the RFID readers. In this subsequent testing phase, we aim to simulate the casing using a plastic material. Specifically, a plastic material will be introduced between the RFID tag and the sensor, replicating real-world conditions. Through this experiment, we will assess whether the presence of the plastic material influences the performance of the RFID system, comparing the results to the previous tests conducted under unobstructed conditions.

By evaluating the impact of the plastic material on the RFID reading capabilities, we can gain valuable insights into the equipment's resilience and adaptability in practical scenarios. This experimental analysis will provide essential data to further refine the design of the casing and optimize the overall performance of the RFID system in real-world environments. The results can be seen in Table III.

Tab. III Testing of RFID in plastic casing.

	Experiments			
	1 cm	2 cm	3 cm	4 cm
PN5180	Passed	Passed	Passed	Failed
PN532	Passed	Passed	Passed	Failed
MFRC522	Passed	Passed	Passed	Failed
WS1850S	Passed	Passed	Passed	Failed
RDM6300	Passed	Passed	Passed	Passed
113020002	Passed	Passed	Passed	Passed

As anticipated, the outcomes align with those observed under standard conditions, as plastic exhibits minimal interference with RFID technology.

Following our comprehensive investigation into the variables influencing RFID performance and their relevance to the company's requirements, it has been determined that an environment characterized by rain and humidity is the most likely scenario in which these assets will be deployed. Consequently, a series of experiments have been designed to evaluate the performance of RFID technology under such conditions. In order to replicate this specific environment, the sensor and the reader were enclosed within a plastic casing, and water was subsequently introduced between the RFID system and the sensor. These tests were conducted to ascertain the system's ability to operate effectively in these challenging circumstances.

The outcomes presented in Table IV demonstrate the favorable performance observed during the rainy test scenario. The close proximity of the NFC-enabled equipment and the nature of the test environment resulted in minimal impact on RFID functionality. These results further validate the system's operational robustness in adverse weather conditions, specifically in the presence of rain.

Tab. IV Testing of RFID in Rainy conditions.

	Experiments			
	1 cm	2 cm	3 cm	4 cm
PN5180	Passed	Passed	Passed	Failed
PN532	Passed	Passed	Passed	Failed
MFRC522	Passed	Passed	Passed	Failed
WS1850S	Passed	Passed	Passed	Failed
RDM6300	Passed	Passed	Passed	Passed
113020002	Passed	Passed	Passed	Passed

Lastly, it is well-established that RFID technology encounters limitations when attempting to read through metallic materials, particularly at frequencies of 13.56MHz and 125kHz. To validate this theoretical understanding and provide empirical evidence, a comprehensive proof-of-concept experiment was conducted. The experimental results unequivocally confirmed that RFID functionality is indeed impeded by the presence of metal.

The empirical findings are meticulously documented in Table Table V, which presents a systematic evaluation of RFID read performance in the presence of aluminum. The table provides crucial insights into the diminished RFID reading capability when faced with metallic obstacles, substantiating the theoretical knowledge with practical evidence.

Tab. V Testing of RFID in aluminum and copper scenarios.

	Experiments			
	1 cm	2 cm	3 cm	4 cm
PN5180	Failed	Failed	Failed	Failed
PN532	Failed	Failed	Failed	Failed
MFRC522	Failed	Failed	Failed	Failed
WS1850S	Failed	Failed	Failed	Failed
RDM6300	Failed	Failed	Failed	Failed
113020002	Failed	Failed	Failed	Failed

6. Discussion

The primary objective of this project was to conduct a comprehensive analysis of the company and evaluate its current state. Various methods were introduced to examine the organization's existing conditions and identify potential challenges within the defined scope of the initial problem formulation. Through this analysis, a crucial finding pertaining to the value chain emerged, indicating that the company invests significant time in asset counting and revealed a gap that could be addressed through gap analysis which revealed a huge gap between what was actual happening and what was the strategic goal.

Consequently, recognizing the need to initiate an asset tracking project as justified by the value chain finding, it became essential to assess the company's level of digital maturity. This evaluation aimed to determine the extent of digitalization within the organization before proceeding with further automation initiatives. The 360DMA was employed for this purpose, revealing several areas of weakness within company's digital framework. Notably, reliance on paper-based processes and email-based order management were identified as areas requiring further digitalization to achieve a balanced digital maturity level, as proposed by the 360DMA assessment.

Despite the low scores in these dimensions, it became evident from the aforementioned results that implementing a real-time tracking system would address the prolonged asset counting process, enable effective asset retrieval, and provide reliable data for improved planning by minimizing unnecessary transportation and enhancing invoice accuracy. Additionally, such a system would contribute to increased customer satisfaction, ensuring timely delivery of ordered goods while enhancing financial stability for the company.

Following the comprehensive assessment of the aforementioned challenges, a final problem formulation was devised with the objective of developing a system capable of effectively addressing these issues. This formulation was further broken down into multiple objectives to guide the project's implementation.

To identify the most suitable technology solution, a meticulous comparative analysis was conducted. Each technology was carefully evaluated against the specific requirements of the problem at hand. After a thorough assessment, passive RFID emerged as the most appropriate choice. While other technologies may possess certain technical advantages, their relative novelty contributes to higher costs at present. Considering the company's equipment-related objectives, economic factors played a significant role in scoring these technologies lower, despite their potentially superior technical capabilities.

Subsequently, in section 5 phase, a system was designed and tested in alignment with the two additional objectives outlined in the final problem formulation. Given the project's time constraints, it was imperative to identify a user-friendly solution that could be easily implemented and maintained with limited development expertise. This requirement was established during the concept development phase.

To meet these criteria, a system was developed by procuring components from the m5stack ecosystem which was the only available full system that could be delivered within the project's limited time. The tracking of assets, a particularly challenging aspect, was emphasized throughout the technology comparison phase. Numerous ideas were explored, and one crucial consideration was the acquisition of reliable data, which posed difficulties due to the metallic nature of the assets. To address this issue, a protective case was developed to eliminate the problem of data unreliability. By focusing on NFC technology and employing this case, weather sealing problems and placement challenges associated with NFC were effectively resolved.

Following rigorous testing in various environments, a fully functional proof of concept was successfully developed. This system enabled asset tracking and facilitated the transmission of data via an API to a cloud server. The accessibility of this data to different systems, including the company's ERP (Enterprise Resource Planning) system, although not subjected to automated testing due to limited access, showcased the versatility and compatibility of the concept. The robustness of the equipment was also verified through extensive testing, confirming the feasibility and efficacy of the proposed solution.

To evaluate the feasibility of the project and ensure alignment with the objectives outlined in the final problem formulation, an economic and implementation analysis was undertaken. This analysis aimed to assess the financial viability of the concept and its potential implementation strategy.

The total cost associated with implementing this concept for all available assets in the realm of assets was calculated to a reasonable price. This expenditure should be viewed as a justifiable investment considering the anticipated value it will bring in terms of saved man-hours for counting and planning, as well as mitigated equipment loss. Moreover, it is crucial to recognize that the implementation should be executed in a phased manner, as described in step of implementation. This approach allows for incremental deployment, enabling early detection of any issues or challenges and reducing the overall risk associated with the project. By adopting this step-wise implementation approach, the costs incurred are significantly lower, thereby minimizing potential losses if adjustments or termination are required at an early stage. Furthermore, it is important to recognize that such systems are characterized by their modularity and flexibility. This means that, in the event that a decision is made to pursue a technically superior technology during or after step 1 of the implementation process, even if it entails increased costs, it remains feasible to incorporate the upgrade. This flexibility ensures that the system can adapt to changing needs and advancements, allowing for future enhancements and improvements that align with the project's objectives. Therefore, if the justification exists to invest in a more advanced technology at a later stage, the modular nature of the system facilitates its integration without significant disruption or complexity.

It is worth noting that the aforementioned cost estimation represents a conservative or pessimistic scenario. However, due to the limited availability of information, an optimistic estimation is currently unavailable. It is essential to acknowledge the potential for significant cost reduction as the project progresses, given the dynamic nature of technology advancements and potential economies of scale.

7. Conclusion

This project aims to develop and execute a proof of concept for a tool that is capable of real-time tracking and collection of relevant data from the company's assets. One of the primary objectives is to assess the functionality of the tool under specific conditions. Moreover, to analyse how this project will enhance the value and knowledge of the company. This was summarised in the problem statement.

"Design and develop a robust and in-dependable tracking system, capable of autonomously monitoring a significant quantity of assets, while ensuring its resilience in diverse environmental conditions, albeit with a potential consideration for cost-effectiveness"

The research group developed a robust and in-dependable tracking system by designing suitable moulds for the placement of RFID readers. Additionally, a control system utilizing the M5Stuck controller has been implemented, which offers straightforward usage instructions and reliable performance. Furthermore, the tracking system has been designed to operate autonomously, ensuring smooth functionality when all equipment is deployed on the track. It is capable of simultaneously counting all the assets, demonstrating its efficiency. Moreover, the system is weatherproof, safeguarding the RFID reader antenna from water damage. Notably, the implementation cost for integrating this system into a single transporting unit is remarkably affordable. The value of the collected data will greatly contribute to the company's productivity and enable the identification of more efficient working methods

Acknowledgement
The authors of this work gratefully acknowledge Grundfos for sponsoring the 11$^{\text{th}}$ MechMan symposium.

References

[1] inpixon. https://www.inpixon.com/, 2023. (Accessed on 05/19/2023).

[2] C. JS., "Lorawan vs. wi-fi in long range wireless applications," March 2019. (Accessed on 05/20/2023).

[3] F. Ahmed, M. Phillips, S. Phillips, and K.-Y. Kim, "Comparative study of seamless asset location and tracking technologies," Procedia Manufacturing, vol. 51, pp. 1138–1145, 2020. 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021).

[4] R. V. course AAU, "Robot vision," 2023. (Accessed on 05/20/2023).

[5] J. Kamauff, Manager's guide to operations management. McGraw Hill Professional, 2009.

[6] S. Nigel, A. Brandon-Jones, and R. Johnson, Operations Management. United Kingdom: Pearson Prentice Hall, 7th ed., June 2013.

[7] G. Blokdyk, Gap Analysis A Complete Guide. Canada: 5STARCooks, June 2019.

[8] B. Lindsley, "The simple guide to problem mapping (only 4 steps)." https://bryanlindsley.com/simple-guide-problem-mapping/, 12 2022. (Accessed on 05/19/2023).

[9] M. Colli, O. Madsen, U. Berger, C. Møller, B. V. Wæhrens, and M. Bockholt, "Contextualizing the outcome of a maturity assessment for industry 4.0," IFAC-PapersOnLine, vol. 51, no. 11, pp. 1347–1352, 2018. 16th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018.

[10] G. Schuh, R. Anderl, J. Gausemeier, M. ten Hompel, and W. Wahlster, Industrie 4.0 maturity index: managing the digital transformation of companies. Herbert Utz Verlag GmbH, 2017.