Enabling Effective Data Collection for Industry 4.0

Technical Solution for Collecting and Transferring Shop Floor Data

Master's thesis in Production Engineering

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Abstract

The manufacturing industry is moving towards Industry 4.0, this requires that the right information is available to reach the full potential of the various Industry 4.0 technologies such as Digital Twin, Cloud computing, advanced analytics, Artificial Intelligence, Internet of Things, and Machine Learning. To obtain the right information, a system for gathering and transferring data in real time is required. To be able to make this connection, Edge device is usually used. Edge devices are devices that can collect data in production.

The purpose of this thesis is to find and evaluate suitable technical solutions to collect and transfer data. The work is carried out in three steps, identifying the data collection challenges, a literature study to find technical solutions, and evaluating technical solutions. The findings show that there are technical solutions on the market to collect and transfer the data that the case company request. Further research should ensure that the technical solutions work by doing tests in a lab environment or by trying to implement them on a workstation.

Keywords: Collecting Data, Data Acquisition System, Data Logging, Data Security, Edge Device, Industry 4.0, Internet of Things, Real-time Monitoring, Transferring Data.

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Alexander Andersson and Carl Lund, Gothenburg, May 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AI	Artificial Intelligence
CBM	Condition Based Maintenance
CPS	Cyber-Physical Systems
D2D	Device-to-device
HMI	Human-Machine Interface
I/O	Input/Output
IIoT	Industrial Internet of Things
IPC	Industrial PC
IP	Internet Protocol
IoT	Internet of Things
IT	Information Technology
KPIs	Key Performance Indicators
LAN	Local Area Network
LTE	Long-Term Evolution
M2M	Machine-to-machine
ML	Machine Learning
MQTT	Message Queuing Telemetry Transport
OASIS	Organization for the Advancement of Structured Information Standards
OPC UA	Open Platform Communications Unified Architecture
OEE	Overall Equipment Effectiveness
PdM	Predictive Maintenance
PLC	Programmable Logic Controller
RQ	Research Question
USB	Universal Serial Bus
VD	Virtual Device
VDcom_v2	Virtual Device Communication Version 2
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Network

Contents

List of Figures

List of Tables

1
Introduction

The introduction will present the foundation for the problem that is to be researched in this thesis. The problem formulation and the case company as well as background to the importance of this topic. Overall, this chapter will provide the basis for understanding the importance of the thesis and the potential impact it can have on case companies' operations and society.

1.1 Background

The rapid advancements in industrialization and informatization techniques have resulted in significant progress toward the development of the next generation of manufacturing technology. As a result, the industry is on the edge toward the fourth industrial revolution, also known as industry 4.0[66].

The progress of IoT is largely supported by four primary drivers: Sensors, Big data analytics, Cloud computing, and Machine-to-machine (M2M) or Device-to-device (D2D) communication. By combining these drivers, remote control and intelligent systems applications can be developed. [22]

Machine Learning (ML) has emerged as a powerful tool in the field of artificial intelligence (AI) for developing intelligent predictive algorithms. With its ability to forecast outcomes based on trained models and historical input data, ML has gained significant attention and has become a widely researched area. There are many problems that prevent companies from implementing Machine learning (ML), some of these can be e.g. Lack of connected machines, Unclear evidence of data that provides value, Without input data, it is not possible to run ML algorithm, and safety risks with connecting machines etc.[71]

The utilization of data mining techniques in manufacturing databases has emerged as a crucial means of acquiring knowledge [70]. The data mining techniques need data from the production system to give insight and knowledge about the production system. An integrated analysis of big data in manufacturing offers benefits across all aspects of the manufacturing process [52]. This shows that taking decisions based on data improves the manufacturing process.

The Internet of Things has introduced brand-new capabilities for manufacturers to detect and address areas that are affecting Overall Equipment Effectiveness (OEE). By using instrumentation and analytics to gain a comprehensive understanding of equipment performance, issues can be identified and resolved in three ways[29]:

- Monitoring key performance indicators (KPIs) for a production line in real-time
- Providing advance warnings of potential equipment degradation or failure to prevent unscheduled downtime
- Analyzing historical process and performance data to optimize maintenance planning, schedules, and resources, resulting in decreased maintenance costs, reduced usage of materials and supplies, and increased equipment availability

In order to perform predictive maintenance (PdM), it is required that there is sufficient useful data that can be used to perform analysis. The more data there is, the more possibilities there are for applying machine learning algorithms. The reason why businesses should investigate PdM is that there can be great economic benefits from implementing it in the business. [71]

To take a step towards Industry 4,0 technologies, such as (Digital Twin, Cloud computing, advanced analytics, Artificial Intelligence, Internet of Things (IoT), and Machine Learning) data with satisfactory quality is needed. The devices closest to the machines and products are called edge devices. This paper aims to put further light on the problem to collect real-time data in a complex production system through a case study to validate if the commercial market can solve the challenges with the new demand for real-time data.

1.2 Aim

The first aim is to provide a technical solution that can both gather real-time data and collect data that the stakeholder's request but are not possible to gather in the previous technical solution. This technical solution will be an enabler for example condition-based maintenance, industry 4.0, and Internet of Things. The second aim is to find processes to collect and transfer data. This creates of optimal production processes that can lead to increased efficiency from both an environmental and economic perspective.

The aim leads to two research questions. Defining the research question is likely the most important step to do in a research study[69]. Question one is formulated to investigate which stakeholders exist, what requirements and wishes they have on the technical solution, and which solutions achieve those requirements and wishes.

1. What technical solutions are available on the market that fulfills the requirements and wishes of the stakeholders?

Question two is chosen to, in an evidence-based way, compare the technical solutions that meet the requirements and to recommend which technical solution is best for Aurobay.

2. How to evaluate the chosen technical solutions based on the requirement specification?

1.3 Objective

The objective of the master thesis is to compile a list of different technical solutions that can collect and transfer data. The technical solution should also meet the requirements of the stakeholders at case companies and give recommendations on which technical solution is optimal for their operations. The objectives will be presented to both the Manufacturing Engineering - management team and the department of Manufacturing Engineering – Intelligent Factory.

Various activities that must be conducted to achieve the objective are stated below:

- Identify stakeholders and make a stakeholder analysis regarding data collection.
- Analyse the requirements and wishes that the stakeholders have on the technical solution for gathering data and compile it in a requirement specification.
- Find and analyze suitable evaluation cases that generate requirements to the requirement specification.
- Find different technical solutions that can transfer collected data.
- Evaluate if the technical solutions meet the requirement specification by conducting a literature study.
- Find a method for ranking the technical solutions that meet all the requirements in the requirement specification.
- Evaluate and recommend which technical solution is most suitable for Aurobay with the found method.

1.4 Case Description

Aurobay has developed and produced powertrain solutions for the car industry for over 100 years, the company separated from Volvo cars in 2021 and become a leader in developing and producing powertrains[14]. The case is conducted in the Aurobay plant located in Skövde which has Machining processes, automatic assembly, and manual assembly.

Aurobay, like many other manufacturing companies, is currently investigating the possibility to make more data-driven decisions by collecting valuable data. For example, an initiative called *Unlocking Plant Floor Data* is currently investigating the possibility to adopt PdM. One challenge for the project is that some data are not automatically collected into a database. One of the core enablers of PdM is that one has a continuous flow of data.

Aurobay has a legacy system for collecting and transferring shop floor data, it has been developed, updated, and adapted in several rounds over decades. A simplification of their data system is that: the system is currently able to handle data for Industry 3.0. Aurobay wants a new technical solution that can transform into industry 4.0. The current system is pushed to its limit and they now want a parallel system that can collect large amounts of data to take their manufacturing process to the next level.

Aurobay wants to take further steps in IoT (Internet of Things) to make this possible they need to collect real-time data. One of the advantages of working with real-time and historical data at the system and component level is that it can make algorithms for rule-based supervision in real-time possible[54].

In this thesis, the main task is to find a technical solution for Aurobay's challenges. When technical solutions are mentioned it refers to a system with both hardware and software solutions that can work together to collect and transfer shop floor data to their database. The new technical solution should meet the requirements of the stakeholders. The technical solutions will be relatively ranked based on the requirements and wishes of the stakeholders.

Simulation engineers at Aurobay currently working to enhance the simulation models with better energy consumption data. With more real-time data as input, it will be possible to validate their models. They use generic data to calculate energy consumption and lack the opportunity to confirm the model. If Aurobay could gather energy-related data with a new technical solution, this could be used as input in the simulations model to get a prediction of the energy consumption for a production line but also validate the model when the simulation becomes reality. Energy consumption is a trending topic that could exemplify the data usage, the data covered in this study should however not be limited to just energy consumption. This example shows that the collected shop floor data can be an enabler to make more, and better data-driven decisions.

Today some of the data for KPI analysis is missing and some are manually collected, this leads to delays and requires large efforts to compile. A technical solution that can handle continuous data flows will ease and expand the possibilities to analyze KPIs.

1.5 Scope and Delimitations

This thesis work will investigate the types of data collection equipment and concepts available on the market that are suitable for Aurobay's existing but also future production systems. The work will develop boundaries by having interviews with key personnel and setting the requirements for the new technical solution. A literature study will then be carried out to deeper understand how others solved similar problems and what technical solutions are available on the market.

This project will not deal with any actual collection or analysis of data. The project should not focus on which kinds of KPIs the data should be used for, and no physical implementation will be made in the factory.

2

Theoretical Framework

In this chapter relevant information regarding different terms and methods will be presented. The chapter is divided into three parts, the first deals with various production-related terms, the second part deals with research methods and the third part handles a brief introduction to various technical solutions that is relevant to understanding and will be used to answer the research questions

2.1 Production Related Framework

In this section, a comprehensive range of techniques and concepts related to production will presented and explained, equipping the reader with a profound understanding of the subject matter. The section will give a context to the thesis, it explains terms that are surrounding the field that will be addressed.

2.1.1 Industry 4.0

Identifying and implementing Industry 4.0 scenarios can be challenging for companies due to the term, industry 4.0, being unclear[31]. Industry 4.0 is an umbrella term Including various of the latest concepts that cannot be precisely categorized within a specific discipline or differentiated from one another in certain cases[49]. Essentially, it indicates a set of, primarily, IT-driven transformations in manufacturing systems[49].

The fourth industrial revolution involves a shift from centrally controlled to decentralized production processes, which is made possible by the communication among people, machines, and resources. In this paradigm shift, smart products have knowledge of their production history, current state, and target state, and are capable of actively guiding themselves through the production process. They achieve this by instructing machines to perform manufacturing tasks and by directing conveyors to transport them to the next production stage.[31]

Industry 4.0 has, for example, led to a rise in digitization, as seen in the adoption of Cyber-Physical Systems (CPS) in manufacturing. These systems involve interconnected networks of humans and robots that collaborate and exchange information, aided by big data and cloud computing, along the entire industrial value chain.[44]

2.1.2 IoT - Internet of Things

IoT involves machine-to-machine communication without human intervention, with a network of devices connected to a computer system, each having a unique identification. These devices can be remotely controlled with exceptional accuracy and efficiency, thus making the system smart. [55]

IoT is a wide term and has some different definitions, for example, one definition found in the literature is:

> *It (IoT) focuses on integration of the physical assets of manufacturing with the cyberspace to form cyber-physical systems.*[41]

2.1.3 CBM - Condition Based Maintenance

Condition-Based Maintenance is also referred to as predictive maintenance (PdM). Condition-Based Maintenance (CBM) utilizes data collected through condition monitoring to suggest maintenance decisions. CBM comprises three primary steps: data acquisition, data processing, and maintenance decision-making. Two crucial advantages of CBM are the ability to make diagnostics and prognostics on the data collected from a production system.[36]

Sensors and other measuring devices have the ability to provide significant knowledge of how the machine performs. By using various types of sensors, it becomes possible to continuously monitor and measure key parameters that are essential for performance evaluation.[68]

2.1.4 Brownfield vs Greenfield

Within the industry, greenfield and brownfield refer to if a system is new or already existing, whereas Greenfield refers to a factory or part of a factory being rebuilt and where modern technologies can be implemented directly into the production facility. Brownfield aims at facilities that have machines and systems that are of different ages and different interfaces. In a Brownfield solution, newer types of systems for data collection are required to coexist with the older systems required for production.[23]

2.1.5 Edge Device

An edge device is a device that communicates between the local network and the physical machine, for example in a production facility [9]. An edge device can collect many different types of data which are then forwarded to the product system where it can be analyzed. An edge device is essential in IIoT as it enables more information acquisition, but it is only used to collect data, it therefore does not interfere with production but only monitors it.

2.2 Research Related Framework

In this section, a number of methodologies that revolves around the subject of this thesis will be presented. The aim is to empower the reader with valuable insights into this domain and a better understanding of the different methods used. This is purely theoretical information this is to create a basic understanding of how the various methods are structured, no focus is placed on how they are applied in the project. How and why the methods are used is explained in the method chapter.

2.2.1 Choosing Stakeholder Analysis Participants

Choosing stakeholder analysis participants is a method for identifying stakeholders [18]. The method starts with step 1 and can then be canceled when enough stakeholders are found. The steps are as follows:

1. Small group makes a preliminary stakeholder analysis with the help of for example, *The basic stakeholder analysis technique*.
2. The potential stakeholders from step 1 are gathered in a brainstorming session to find other potential stakeholders. In the case of Aurobay this can be problematic due to schedule reasons and the sessions can be divided into different sessions to save time in the project.
3. Then the group of potential stakeholders should reflect on who is not attending the group, and who should attend the following meetings.
4. After this the group is complete, however, one needs to go through the earlier steps update and correct the analysis based on the new group.
5. Last step, divide the group into the roles they will have in the project, for example, sponsors and champions, coordinating group, planning team, and various advisory or support groups.

2.2.2 Stakeholder Analysis and Stakeholder Participation

The method is based on the following three steps: [11]:

Step 1: Define stakeholders and categorize them based on primary, secondary, and key

The first part of this step is to find and define the stakeholders. The second part is to categorize the stakeholders. They are categorized into primary and secondary stakeholders. Primary stakeholders are the stakeholders who are directly affected positively or negatively by the results of this project. Secondary stakeholders are for example the stakeholders that implement and monitor the project but could also be governments and their regulations.

Step 2: Make a stakeholder table

The second step is to create a stakeholder table to visually compare the stakeholders. The table could for example have an influence on the x-axis and power on the y-axis.

The points below are used as a basis for a brainstorming session to break down the stakeholders.

- Interests that are in relation to the objectives and problems of the project should be identified.
- Rank stakeholders depending on how important it is that they are satisfied with the project.
- The impact that the project likely will have on each of the stakeholder's interests(positive, negative, or unknown).
- The project's relative priority among the stakeholder's interests should be presented.

The ranking of influence is based on the question:
for which stakeholders does the project place a priority on meeting their needs, interests, and expectations? The ranking of power is based on the authority to affect the direction of the project.

Step 3: Risk and assumptions that can affect the outcome of the project should be identified
The third step is to determine the potential risks and assumptions that will impact the project's design and define the criteria for achieving success.

2.2.3 The Interview Protocol Refinement Framework

To ensure the quality of the interviews a process for refinement is used. The interview protocol refinement is a process of four steps [19]. Below the four steps from the method are explained.

Step 1: Ensuring Interview Questions Align with Research Questions
By focusing on the alignment between interview questions and the research questions in the first phase, the usefulness of interview questions in the research process can be enhanced by confirming their relevance, while eliminating unnecessary ones to ensure their importance for the study.

Step 2: Constructing an Inquiry-based Conversation
The interview questions are not the same as the research questions, but they are connected, they should be open-ended, relevant, and focused on the research topic. The interview must follow social rules for a normal conversation. There should be a variety of questions with likely follow-up questions.

Step 3: Receiving Feedback on Interview Protocols
Hand out the protocol for feedback from someone with knowledge of the project to enhance its reliability as a research tool.

Step 4: Piloting the Interview Protocol
During the first interview, extra attention should be paid to ensure that the questions

are interpreted correctly and that things flow smoothly. It should also be ensured that the interview provides as much information as expected.

2.2.4 Gemba

Gemba, a term derived from Japanese, is employed by Toyota to refer to the specific location within an organization where value-added work takes place. Gemba emphasizes the act of physically walking the process and observing firsthand where the value-creating tasks are performed.[37]

Below a six-step guide for conducting Gemba is displayed. The guide put emphasis on meeting the operators in the production and engaging in the problem with them, where the problem arises.

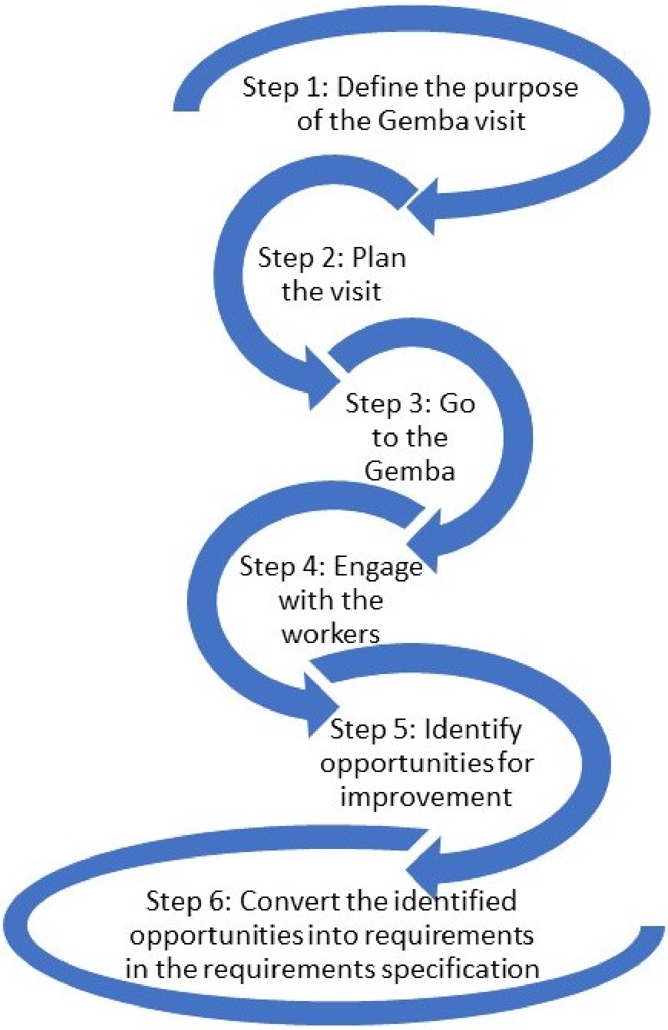

Figure 2.1: Step guide for Gemba

2.2.5 Snowballing Procedure

Snowballing procedure (also known as systematic literature review) is a method for conducting a literature study [65]. The method is presented in figure 2.2.

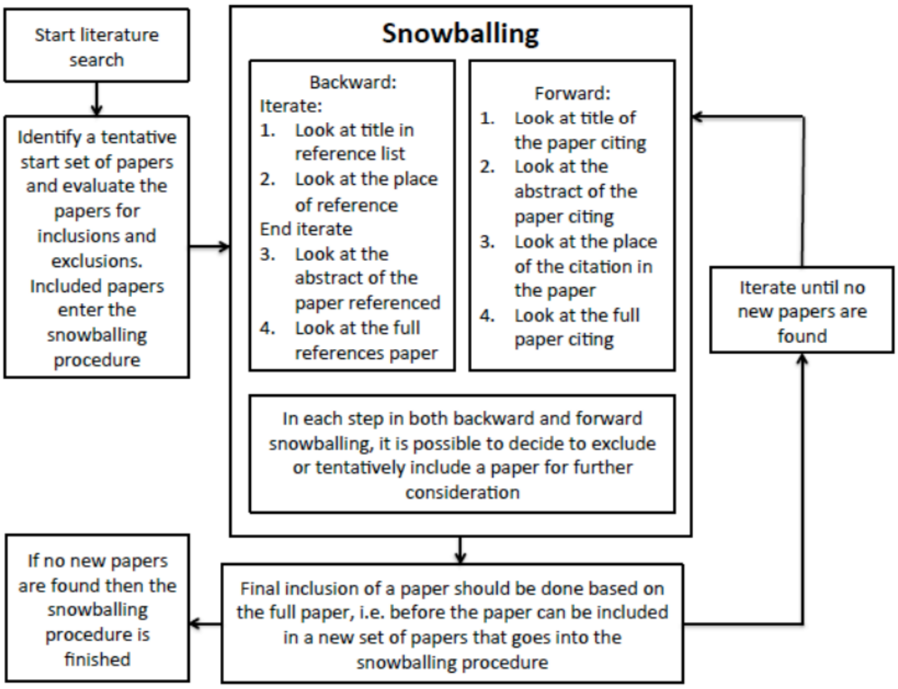

Figure 2.2: Snowballing Procedure [65]

The first step is to find relevant articles that provide a broad and nuanced approach to the field. Start by analyzing and reading all the articles included in the initial set of papers.

The second step is to do backward snowballing, which means listing and checking the reference list among the initial papers. The checking includes that the paper needs to meet a basic requirement, which for example could be:

- Language, they need to be written in English.
- Publication year.
- Has not been analyzed before in the study.

After this the abstract and other key areas are read, one read until you get an idea of whether the paper should be included or excluded in the literature study.

Forward snowballing means checking who has cited the paper that is being examined. Otherwise, the procedure of sorting out the sources is similar to that in backward snowballing. The new paper that is included after the first iteration of snowballing is used as the basis for the next iteration of snowballing, this can be repeated as many times as needed.

2.2.6 Pugh

The Pugh matrix is based on different criteria from the stakeholders, design parameters, or project goals to evaluate different products, services, or processes. These criteria should be objective and take out the guesswork when evaluating the different solutions.[35]

Once the criteria are determined, assign weights to each criterion based on its importance. This weighting process helps prioritize the criteria and evaluates accurately reflects their significance. Additionally, select one alternative as the baseline, which can be the current method or model or any other alternative chosen.[35]

To evaluate the alternatives, compare each one to the baseline. Assess whether an alternative is better, worse, or about the same as the baseline in terms of the identified criteria. The symbols "+," "++," "-", "–," or "=" to represent the scores. The number of positive, negative, and equal are summed up and used to scores for each alternative. Multiply these scores by the respective weights assigned to each criterion and calculate the weighted sums vertically.[35]

Finally, one more iteration is made and refine the analysis. The strongest solution is identified based on the evaluation results. If the results are confirmed, proceed with the selected solution. If not, continue analyzing and improving the alternatives until a strong solution emerges. By conducting multiple iterations and refining the solutions, one can achieve controlled convergence and arrive at a better solution that effectively meets the project goals.[35] An example of how the matrix looks can be seen below:

Table 2.1: Explanation of Pugh Matrix

Criteria's	Criteria rating	Technical solution 1 (reference)	Technical solution 2	Technical solution 3	Technical solution 4
Key Criteria 1	20%	0			
Key Criteria 2	20%	0			
Key Criteria 3	20%	0			
Key Criteria 4	20%	0			
Key Criteria 5	20%	0			
Sum of =		0			
Sum of +		0			
Sum of -		0			
Weighted +					
Weighted -					
Rank					

2.3 Introduction to Technical Solutions

A brief description of the various technical solutions that will be evaluated in the project is provided. This information is important since it provides knowledge about the technical solutions and protocols that are analyzed in the report to answer RQ1 and RQ2. The section is divided into two subsections, one for protocols and one for hardware solutions. The different technical solutions send the data using different protocols. These protocols have slightly different characteristics that make it worth treating them separately from the hardware.

2.3.1 Protocols

OPC UA

OPC UA stands for Open Platform Communications Unified Architecture. The OPC Foundation developed the OPC UA protocol as an advanced, platform-independent, service-oriented architecture that offers capabilities beyond the basics, including discovery, address space, data modeling, and security. OPC UA uses a standard client-server mechanism, with the server featuring an information model that organizes data in a structured format.[67]

MQTT

MQTT is an open message protocol that positions itself as an extremely lightweight publish/subscribe machine-to-machine and Internet of Things connectivity protocol. It prioritizes a small code footprint and low network bandwidth usage while being capable of handling high latency or poor network connections, making it ideal for communication between sensors via satellite link. Since 2013, MQTT has been standardized by the Organization for the Advancement of Structured Information Standards (OASIS) as the protocol for the Internet of Things. In MQTT, an MQTT-Server, also known as a broker, stores the complete data of all communication partners. Small devices report data to the broker, eliminating the need to store the data themselves.[40]

2.3.2 Hardware Solutions

ExperLogger
Accurate measurement data can be acquired, stored independently, and transmitted to the internet or a PC for evaluation using USB, LAN, WLAN, or LTE with MQTT. When using WWAN (wireless wide area network), data can be accessed in real-time.[7]

IXON Cloud IOT
IXON is a cloud-based industrial automation and IoT platform that provides a com-

prehensive solution for remote access, monitoring, and data collection. One of the features of the IXON platform is its ability to collect and analyze data from various industrial devices and machines. The IXON Cloud IOT is capable of generating and transferring data in real time.[38][17]

Sparkplug
Sparkplug is an open-source software specification that provides MQTT clients with a framework to seamlessly integrate data originating from their applications, sensors, devices, and gateways into the MQTT Infrastructure. The utilization of Sparkplug facilitates the incorporation of data from various sources into the MQTT infrastructure in a consistent manner.[26]

MachineMetrics Edge Hardware
The MachineMetrics Edge Platform presents an easily scalable answer for manufacturers, which they can self-install to effortlessly gather data from any machinery and promptly obtain valuable machine insights. The platform supports universal data collection through Plug-and-Play functionality for PLCs that use open protocols.[47]

ioLogik E1200 Series
With support for commonly used protocols (including OPC UA) for retrieving I/O data, the ioLogik E1200 Series is capable of handling a diverse range of applications. This series retrieves I/O data and converts it into OPC UA protocol, enabling easy and seamless connectivity for data applications.[32]

s7-1200 OPC UA
In this technical solution, the OPC UA(described above) is combined with a SIMATIC S7-1200 controller by Siemens. These controllers are compact automation solutions that offer extended communication options and integrated technology functions. They are highly flexible and efficient, suitable for automating tasks in the lower to medium performance range. Additionally, they come equipped with a wide range of technological functions, integrated communication capabilities, and a space-saving design.[59]

Brownfield Connectivity
Siemens Brownfield Connectivity is a connectivity solution offered by Siemens, it is designed for existing industrial facilities or systems, known as brownfield installations (see section 2.1.4). Siemens Brownfield Connectivity solutions aim to bridge the gap between existing industrial infrastructures and the digital era, enabling companies to leverage the benefits of Industry 4.0 and digital transformation without the need for complete system overhauls. Siemens Brownfield Connectivity.[60]

3
Methodology

This chapter will include the diffident methods that are used to carry out the thesis work. The chapter begins with an overview of how the project will be carried out and then provides more in-depth descriptions of the various sub-tasks

To reach the aim of the project, several different methods are used. This is to finally be able to answer the research questions. The research approach is divided into three steps, *Identifying the data collection challenges*, *Literature study to evaluate technical solutions*, and *Recommend technical solutions.* The goal of the two first steps is to answer research question 1 and the third one is to answer research question 2.

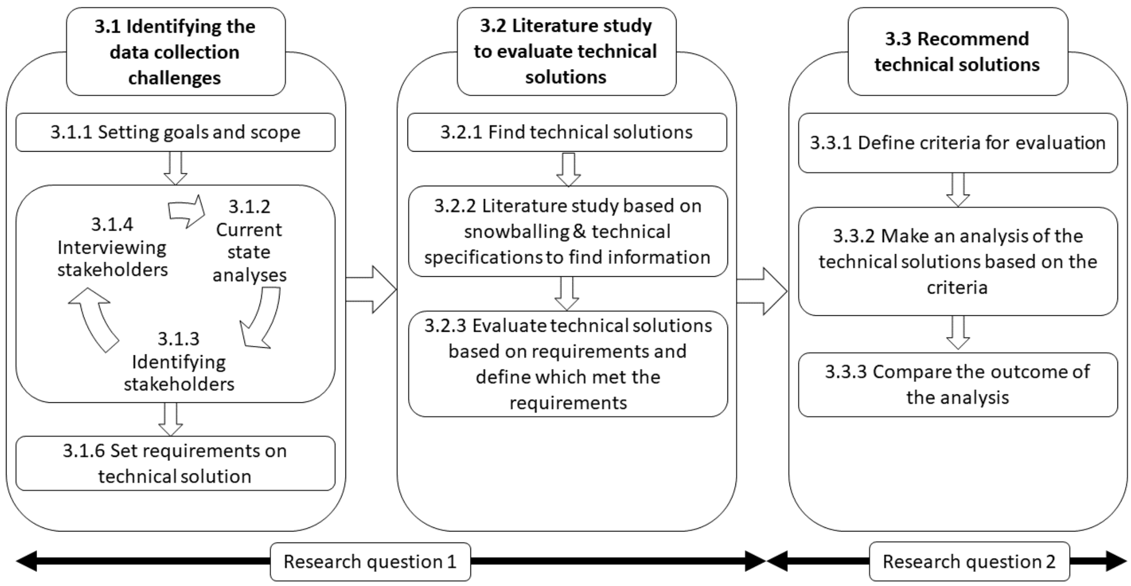

Figure 3.1: Explanation of Applied Research Approach

The study began with *Identifying the Data Collection Challenges* which was a planning phase that focused on setting goals and forming a scope for the project, which was documented in the form of a planning report. After that, stakeholders had to be identified and analyzed, and they became the basis of the current state analysis. More interviews were held with the stakeholders in this phase. Afterward, the focus was then to compile requirements and wishes into a requirement specification. The requirement specification also included requirements from evaluation cases that were chosen with the help of the stakeholders.

The second step was a *Literature Study to Evaluate Technical Solutions*, the technical solutions are found by searching on the internet and by consultation with internal stakeholders. A literature study based on the snowballing procedure is carried out to investigate which technical solutions meet the requirements in the requirements specification. To complete the gaps that exist after snowballing, technical specifications are used to find more information. When all information is gathered regarding which requirements are met, a final answer to research question 1 can be made.

Finally, the last step *Recommend Technical Solutions* was done. A method for evaluating and recommending the technical solutions that met all the requirements was then developed and used to give Aurobay recommendations. The evaluation was done based on the criteria. When the technical solutions were analyzed, a comparison among the analyses was made. This was the answer to research question 2.

3.1 Identifying the Data Collection Challenges

3.1.1 Setting Goals and scope

This was part of the preparatory work, a preliminary method was set for the project as well as a schedule for the course of the project. Objectives regarding how far along the project should be at different time stages were defined. During this part, the focus was to define the problem and the aim, this was done in consultation with the case company and the supervisors from Chalmers.

3.1.2 Current State Analysis

In order to create a deep understanding of this complex data system and its challenges, it was required that information was gathered about the data handling systems. Understanding today's system was vital to being able to understand how a new system could improve data collection.

The current state analysis will focus on how, and what type of data is collected today. This will mainly be done through qualitative interviews with key personnel that is working with data today. The current state analysis should although not limit the evaluation of different concepts, it could be seen as a knowledge acquisition to gain a deeper understanding of the problem from both those who "produce" the data in the factory and those who want to use the data for different types of analysis.

3.1.3 Stakeholders

Stakeholder inputs are important as it is an effective way of gathering information that can be difficult to obtain in other ways[10]. Stakeholder identification and analysis were carried out to bring in key persons who could contribute information that helped the project forward.

Stakeholder Identification

Stakeholder identification is important since it identifies the people and departments that are dependent on the system and has great knowledge about it. This means that information is obtained from the people who have in-depth knowledge of the current system, but they are also the same people who likely will be affected by the new system. The method chosen is developed to gain information, build political acceptance and approach important questions concerning legitimacy, representation, and credibility [18].

The stakeholders were primarily identified through a version of a five-step method called "Choosing stakeholder analysis participants" [18]. The names of personnel are changed to codenames. A challenge in the project was that the case company had many production lines that were similar to each other. In order to limit the stakeholders, a selection needed to be made where different types of production lines were represented. This was done to provide a wider selection without increasing the number of stakeholders.

First, a small group was conducted for the first brainstorming session. The brainstorming was held in a conference room and all participants had time to prepare before the meeting. The meeting time was set to one hour. The outcome was two new stakeholders.

The new stakeholders, together with the old stakeholders, conducted one more brainstorming session under the same circumstances, with the exception that an extra 30 minutes were added since more people attended the meeting. The outcome of the session was 4 new stakeholders. The total number of stakeholders in the analysis became seven.

Stakeholder Analysis

In order to get an idea of who in the company would be affected by the implementation and on what level, a stakeholder analysis is done to take into account their demands and wishes regarding the new technical solution. Another important aspect is that they must understand what the project's goals are, in order to free up time for the employees to, for example, participate in interviews for the project [11].

The method used for stakeholder analysis is *Stakeholder analysis and stakeholder participation*, which is a 3-step model[19]. The first part in *Step 1* is to find the stakeholders, this is done earlier in section 3.1.3. The second part of the first step is to categorize them and the *second step* is to identify if there are any interests that are in relation to the objectives and problems of the project. All stakeholders from the stakeholder identification are reviewed according to steps 1 and 2.

3.1.4 Interviews with Stakeholders

By having semi-structured interviews with stakeholders at the case company, an understanding of the requirements and wishes of the stakeholders was gained. The names of the interviewees are changed to codenames. *The Interview Protocol Refinement Framework* was used to improve the quality of the interview, which likely led to better information being gathered during the interview [19].

The interviews were combined with the current state interviews, aiming to minimize the working time that the employees needed to use for the interviews. The time allocated for the interviews was 30 minutes. When performing the interviews, one person focuses on asking questions, and the other takes notes. The interviews are held in both Swedish and English, depending on what the interviewee prefers, and then the interviews are translated into English. The interviews were done at the: *Department of Intelligent factory*, *Unlocking Plant Floor Data*, *Assembly line*, *Machining line*, *Software developers – PLC*, *Energy consumption simulation* and *IT security*.

The steps in the Interview Protocol Refinement Framework is used:

Step 1: Ensuring interview questions align with research questions
To obtain a better understanding of the current state, the first two interview questions were formulated. These questions are formulated to provide a better overview and insight into the current state of the systems and what data is missing today.

Question three is formulated so information about what is critical to think of when looking at implementing a new data collection and what a new solution should not affect. This is asked to get a better understanding of what is critical in the production.

Question four is asked to get information on what the people that are working with data collection think is important when looking into new solutions on how data can be collected. This question will provide information about the requirements for the new technical solutions.

Additionally, to gather valuable input from the stakeholders on evaluation cases, the last question where formulated. The intention behind this question is to obtain specific suggestions for evaluation cases that would be suitable for the evaluation of the new technical solution. all the questions are presented below.

1. What kind of data could facilitate your workload?
2. What do you feel is the biggest problem with Aurobay's data collection today?
3. What consequences must the data collection process not have on your depart-

ment?
4. Do you have any other requirements or wishes regarding the data collection?
5. Do you have any suggestions on specific evaluation cases that could be good for evaluating the technical solution?

Step 2: Constructing an inquiry-based conversation
Questions 1 and 2 are connected to the research since it adds information to the current state analysis which is important for the project. Questions 3 and 4 are directly connected to the research question. All questions are open-ended and focused to give information to gain valuable information.

Step 3: Receiving feedback on interview protocols
The supervisor's feedback on the interview protocol is used to enhance its reliability as a research tool. Feedback was obtained by sending the protocol to the supervisor and getting the chance to leave feedback.

Step 4: Piloting the interview protocol
The first interview has held with the supervisor from the case company, after the interview, she had the possibility to leave feedback on the questions and it was also ensured that the questions were correctly interpreted.

3.1.5 Evaluation Cases

Evaluation cases were real-case scenarios from the case company where the technical solution could be used. To validate the technical solution in a practical real scenario, the evaluation cases were chosen in cooperation with the stakeholders. This was done to create a more realistic requirement specification.

Identify Evaluation Case
The evaluation cases were identified through discussions with the stakeholders. Based on what the stakeholders identified as cases that could be improved with the help of data collection. To make it doable in the time span of the thesis, three cases were chosen among the recommended cases from stakeholders. The chosen cases should not be similar but rather capture various problems in production.

Find Requirements from Evaluation Cases
The requirements were set by doing Gemba in the production and conducting interviews. Gemba was chosen because it enabled a focus on actual production problems and a clear connection to real everyday problems for the staff. It led to more specific requirements based on knowledge from those who work closest to the machinery and knew which data was critical. The method for Gemba used in this project is explained in figure 2.1.

The Gemba was done at the *Processing line of the cylinder heads*, *assembly line of inner and outer components*, and various energy-consuming machines in the production. The time booked for the Gemba was 1 hour, which was more than what was needed. This was to create time to discuss and reflect without feeling time pressure. During the Gemba, notes and photos were taken for further analysis.

3.1.6 Set Requirements on Technical Solution

In this section, the requirements specified from the interviews with stakeholders and from the evaluation cases were compiled into one table. The duplicates and similar requirements and wishes were merged into one requirement or wish.

3.2 Literature Study to Evaluate Technical Solutions

The literature study was used as a tool to find source-critical information about various technical solutions. By going through literature that contains technical solutions for data collection, one could also come across new technical solutions that were relevant to the problem. The purpose of the literature study was to find information regarding the technical solutions and to evaluate if they met the requirements set by stakeholders and evaluation cases.

The range of literature regarding technical solutions varied widely and often depended on how established the solution was on the market and how long it had been on the market. To analyze new and less established technical solutions, a mixed literature study was used. The first approach involved finding information through a modified version of snowballing[65]. If the information could not be found through snowballing, the following step was to search for technical specifications from the company that produces or sells the solution, if the information could not be obtained through snowballing. However, it is important to note that the latter approach may present biased information since it comes directly from the company with a commercial interest, while snowballing often involves information from third-party academic sources.

3.2.1 Find Technical Solutions

The technical solutions were identified through a combination of targeted keyword searches on internet-based search engines and consultation with internal stakeholders. Several technical solutions came from internal stakeholders, during the interviews, who encountered the solutions during previous work experiences. Potential solutions were sourced by identifying companies that provide relevant technical products or services. Different combinations of keywords were used, examples of keywords included: *Edge device production*, *IoT communication protocols*, and *Industrial data logging solutions*.

3.2.2 Literature study based on snowballing & technical specifications to find information

The main method chosen for the literature study is a modified version of the snowballing procedure (also known as systematic literature review). A key benefit of snowballing is that it initiates the research process with relevant papers and subsequently utilizes them to guide further study [65]. The problem with a conventional literature study in this project was that relevant keywords resulted in a large number of articles, but the proportion of relevant articles was low.

To find the initial papers for the snowballing, different combinations of the product name and the company names were used as keywords in Scopus and Google Scholar. The modification was made to streamline the process of conducting the snowballing literature study, and a task-specific stopping criterion was employed. The goal of this literature study was to determine whether the technical solutions meet the requirements outlined in the requirement specification. If it was discovered that a particular technical solution failed to meet any of the requirements, the literature study for that solution was stopped. So the stopping criterion was that if the technical solution did not meet one of the requirements or had met all requirements, the literature study for the unique technical solution was stopped.

Technical specifications are also used to find information by searching on the company web pages, one can often find technical specifications and information regarding the technical solution. There are also often data sheets or catalogs about the technical solution that can be used as a basis for the literature study. This information can be used as input when evaluating technical solutions.

3.2.3 Evaluate technical solutions based on requirements and define which met the requirements

By compiling a table with the requirements and wishes in the first column and the technical solutions in the first row an easy overview of the technical solutions that met the requirements can be done. With the help of this table, one can then define which technical solutions reached the requirements shown in the requirements specification.

3.3 Recommend Technical Solutions

This section of the report is dedicated to describing methods to answer research question 2: *How to evaluate the chosen technical solutions based on the requirement specification?* The technical solutions that met the requirements in the requirements specification must be further analyzed to find the pros and cons of the solutions. Previously, all requirements were evaluated, and in this analysis, new criteria will be evaluated.

The Pugh matrix is a valuable tool for evaluating potential solutions by systematically assessing their strengths and weaknesses. It allows for a structured comparison of alternatives and identifies strengths and weaknesses. Through iterative analysis, the matrix convergence towards an optimal solution. It provides a comprehensive view of the relative merits of different alternatives, guiding the decision-making process and promoting the development of an improved solution that aligns with project objectives. By actively considering and addressing the strengths and weaknesses of each option, the Pugh matrix helps to achieve a more robust and effective solution.[35]

Since Pugh is a systematic way of comparing different concepts and generates convergence towards the most optimal solution, it is suitable for answering RQ2. Pugh helps to objectify complex problems with multiple parameters so that the "guessing game" is minimized, this is good because the problem analyzed in the report is complex and multidisciplinary.

3.3.1 Define criteria for evaluation

The first step when doing a Pugh matrix is to find evaluation criteria. A meeting of 1 hour was booked with the supervisor at the company to discuss the criteria to use in the Pugh matrix. The meeting was in the form of a brainstorming session where important criteria to evaluate the technical solutions were identified. The weight of the criteria where also discussed and set. The criteria capture some of the most important aspects that should be compared. The criteria used in the Pugh matrix are listed below with respective weight:

1. 25%: The solution is not dependent on PLC to work
2. 15%: Installation & Configuration
3. 10%: Stability of the company
4. 10%: Product maturity
5. 40%: It-Security level

3.3.2 Analysis of the technical solutions

The technical solutions that made it thru the requirement specification are the ones that will be evaluated in the Pugh matrix. They are evaluated based on the criteria that are mentioned in the previous section. This evaluation is done in two iterations to make sure the evaluation is valid and will end up with the same result regardless of which technical solution is set as the reference.

3.3.3 Outcome of the analysis

The result in the Pugh matrix is then analyzed. The different iterations are compared to each other, and patterns and other observations are commented on. This is the final result that gets presented to the case company and the answer to RQ2.

4
Result

In this chapter, the result will be presented and it will be divided into three sections. Section 4.1 will handle what the current system looks like and what challenges there are with it are presented. In section 4.2, RQ1 will be answered and the findings from the literature study presented. In the final section 4.3, an evaluation of the technical solutions will be presented and answer RQ2. How the chapter is structured is shown below.

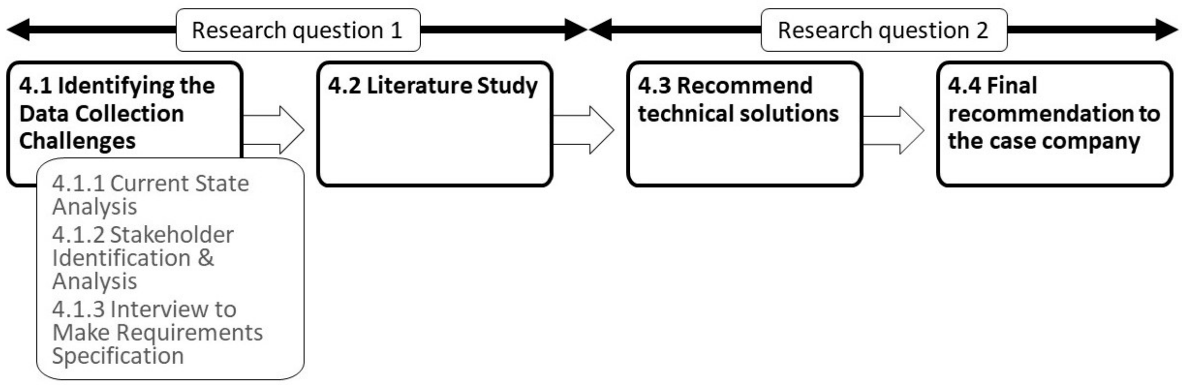

Figure 4.1: Structure of Result Chapter

4.1 Identifying the Data Collection Challenges

In this section information about what today's system looks like and how data is collected today, a large part of the information collection is done through interviews. this information will be used for identifying both stakeholders to a new technical solution and to understand the limitations that exist with today's system.

4.1.1 Current State Analysis

Today telegram-based technical solutions are used for gathering data in different manufacturing engineering cases. This becomes a problem since it's communicating with the PLC program which must be custom-made for each system. The customization is a communication module and function block that is added to the PLC called VDcom_v2 which sends data to a system called Virtual Device, VD. The VDcom_v2 block only works with Siemens PLC.

VD is used for manufacturing orders, control information, and results. The system can be custom-made for different machines to gather other types of data. Since Aurobay has many different machines and devices, they have to make a lot of customizations to collect the data by telegram in the VDCom_v2-system, another disadvantage is that the VDCom_v2-system sends a large amount of data, and one cannot request only one type of data. Some of the data is not possible to collect in an automated way and needs to be collected manually via a USB stick. The figure below shows a simplification of the current data flow in Aurobay's production. In the example two databases are shown, however, there are more databases.

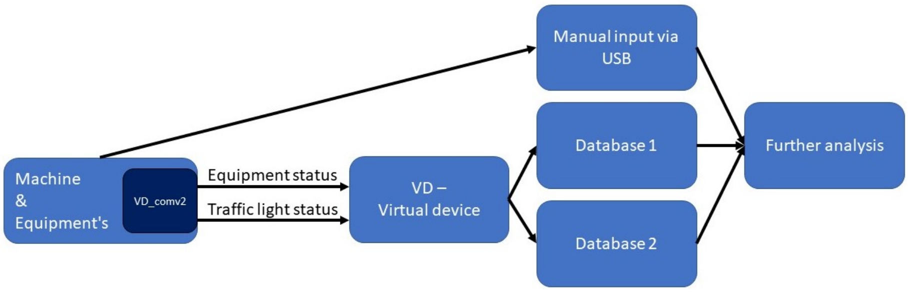

Figure 4.2: Simplification of data flow at Aurobay

Aurobay wants to eliminate manual data collection by using some kind of technical solution that can, in an automated way, collect data. Aurobay wants a standardized technical solution that should be able to collect different kinds of production data, examples of types of data will be analyzed in the *current stat analysis* to make sure that the requirements and wishes of the stakeholders are met. The reason for using a standardized technical solution is that the VDCom_v2-system can't handle all types of data and needs the PLC to be custom-made for the requested data. It is more efficient to maintain the system if it is standardized and the same solution is used to collect data. Another advantage of a standardized technical solution is that it is easier and more cost-effective to implement the system for data collection.

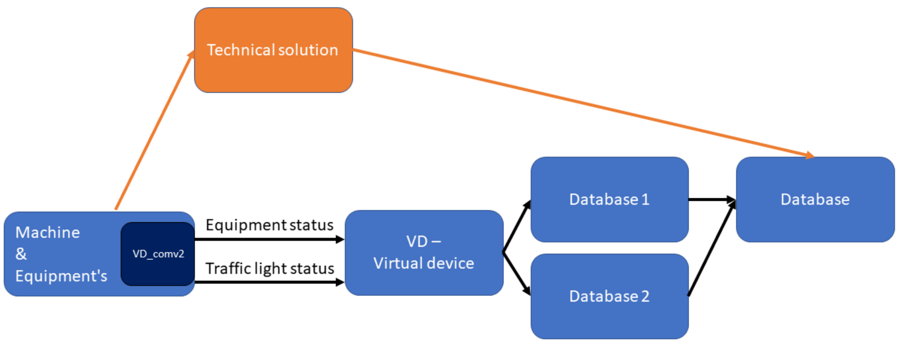

Figure 4.3: Simplification of the new data flow Aurobay is requesting

VD (Virtual device)
VD is a server that handles and redirects large parts of the data that comes from production today. The data gets sent to VD-system which can then perform operations and divide the data and then send it to several different databases. PLC normally has a low data power and therefore calculations and divisions are made in the VD-system because it is a server with considerably more data power.

VDcom_v2
VDcom_v2 is a function block and communication module that is implemented in the PLC for the various equipment in the production system which communicates with VD-system. Telegrams are sent to the VD system when various events in the PLC are triggered.

4.1.2 Stakeholder Identification & Analysis

Throughout the stakeholder identification, seven different stakeholders were identified, for more in-depth knowledge see appendix A.1. The categorization of primary and secondary stakeholders is explained in detail in appendix A.2.

Table 4.1: Identified Stakeholders

Stakeholder	**Short description**	**Primary/ Secondary**
Department of Intelligent factory	Initiated this master's thesis since they have identified a need for an extended collection of real-time data	Secondary
Unlocking Plant Floor Data	Project for adopting condition-based maintenance	Secondary
Assembly line	Typical assembly line at case company	Primary
Machining line	Typical machining line at case company	Primary
Software developers – PLC	Developers who are responsible for the current system	Secondary
Energy consumption simulation	Simulation engineer who wants data to make better simulations	Secondary
IT security	Provides information regarding policies for data security	Secondary

Stakeholder Table
First, a ranking based on the importance to satisfy the stakeholders is done to break down the stakeholders. The Department of Intelligent factory gets the highest ranking since they have initiated the project and the technical solution must full fill their

requirements, they have much power over the project. They also get a high ranking on influence because it will affect how they work with live data.

Machining & assembly ends up in shared second place, they do not have the same power to control the project as the department of intelligent factory, but is important to get all the information required to implement the new technical solution. They get a high ranking on the influence scale since they will be affected by the newly collected data in their everyday work.

IT security is ranked in 3rd place because the project has to follow the rules and requirements that the company has when it comes to handling data. They are not influenced by the project and are therefore placed low on the influence scale, but because the project must comply with the rules and requirements they set, they get a relatively high ranking on the power scale

The other stakeholders are seen as sources of information for the project and do not have much requirement on how the data will be collected. The reason why they are identified as stakeholders is that they have a lot of information that is required to evaluate the new technical solution.

Unlocking Plant Floor Data is ranked above the Energy consumption simulation since it can potentially have a greater impact than the simulations. Software developers – PLC has the lowest power and influence since the outcome of the project would not affect them, it should work in parallel with the already existing systems.

The stakeholders' importance to be satisfied is indicated in the list below:

1. Department of Intelligent factory
2. Machining & Assembly line
3. IT security
4. Unlocking Plant Floor Data
5. Energy consumption simulation
6. Software developers – PLC

The power and influence of the stakeholders are visualized in figure 4.4. The power represents how much a stakeholder can control the project with inputs and requirements, the Influence is how much the project can be expected to influence a stakeholder in their work

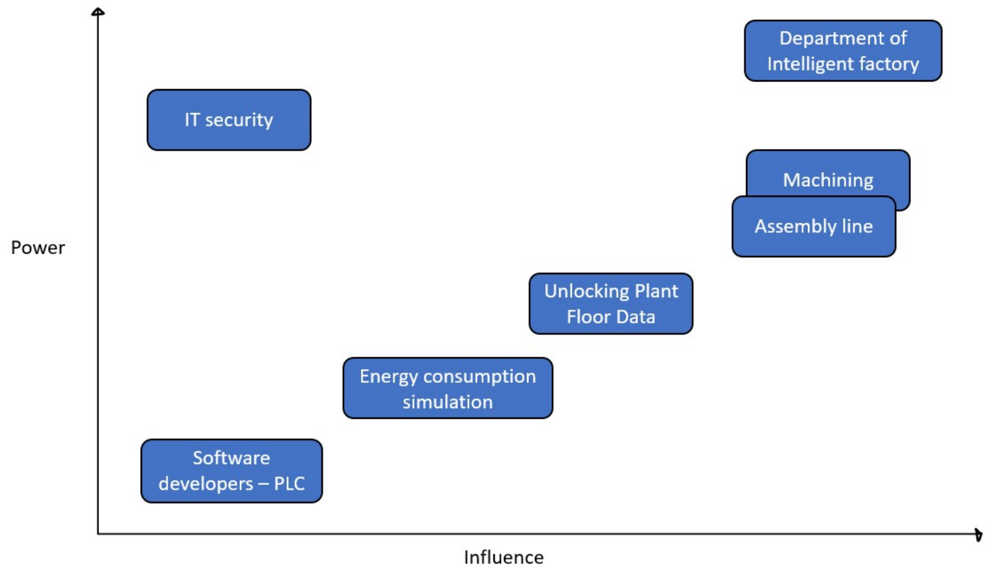

Figure 4.4: Stakeholder Table

Risks and Assumptions
The *third step* is carried out below:
One risk is that the departments of machining and assembly will directly affect the department, this could be both positive and negative depending on the technical solution. This could have the effect that they leave information that can affect their work tasks in a beneficial way.

Aurobay has several production departments and a complex production unit, so it is difficult to ensure that all different types of stakeholders have had their say. For example, a machining department has been interviewed, but since all machining departments are different, there is a risk of missing information. However, not interviewing everyone is necessary in order to limit the scope to a reasonable level for the time of the project. This makes it difficult to ensure that the analysis was successful, in the event of a possible implementation, it may be discovered that important stakeholders have been missed, but before implementation, it is difficult to say whether the analysis was successful.

4.1.3 Interview to Make Requirements Specification

Key Takeaways from Interviews

Notes from the interviews with the stakeholder are provided in the appendix C.1-C.6. The most relevant answer to the interview questions will be mentioned below:

1. What kind of data could facilitate your workload?
When talking to *Energy Simulation Engineer* he stated that there is an information

gap regarding the consumption of individual equipment and machines. For example, there is no automated way to collect energy consumption data, they need to request an electrician to go and measure for some hours and manually collect the data. They also lack data regarding *average time between failures* and *mean time to repair*. As a simulation engineer, he wishes that this type of data was based on statistics from the production.

2. What do you feel is the biggest problem with Aurobay's data collection today?
The software developers state that one of the biggest problems with data collection is their use of a telegram-based solution. This method restricts them from collecting continuous data or images, which are sometimes required. Additionally, telegrams are limited to 8000 bytes each. If the data exceeds this limit, it needs to be split into multiple telegrams, making it complex and impractical for the receiver to arrange the data.

3. What consequences must the data collection process not have on your department?
The *IT security department* marks clearly that messages can not be sent in an unencrypted form (excluding messages within the industrial network). This is a part of the IT security policy and something that must be fulfilled.

In the interview with the *Assembly Department*, he marks that it is vital that the technical solution must not affect the takt time on the assembly line. Affecting the flow negatively creates negative consequences with a large impact.

4. Do you have any other requirements or wishes regarding the data collection?
Askros,*Department of Intelligent Factory*, emphasized that the technical solution should not negatively impact production takt time. It was also explicitly stated that the system should be considered a complement to VDcomv_2.

5. Do you have any suggestions on specific evaluation cases that could be good for evaluating the technical solution
During the interview at *Machining Department* they recommended contacting a Line technician in the processing line of the cylinder heads to identify and create an evaluation case concerning the washing of components.

The interviewee at *Assembly Department* addressed the problem of conducting alarm logs, the problem is that they need to manually the data via USB at the machine, this is done once a week, and he wants this to happen automatically in real-time.

Regarding the interview with *Energy Simulation Engineers*, a contact person was recommended who works as an Energy optimizer, to gain a more tangible understanding of measuring and recording energy data.
Key Takeaways from Evaluation Cases

The three evaluation cases that were identified: *machining evaluation case*, *assembly evaluation case* and *energy simulation evaluation case* (detailed analysis in appendix C.7, C.8 and C.9. The name of the case indicates which stakeholder has recommended the case.

One common takeaway from the machining and energy simulation cases is that they require measuring and transferring an output current of 4 to 20 mA from a sensor. Another requirement was that the solution required to automatically and in real-time collect alarm logs from the PLC.

The *Machining evaluation cases* states that is important that the technical solution should not consume time or disrupt machining production. This can be rephrased as it should not affect the takt time. Another requirement is they want to easily visualize a graph depicting pressure across multiple cycles.

Merge of Requirements
In appendix C all the requirements and wishes of each stakeholder can be found. The merges are shown in table 4.2 & 4.3 and are done based on the factor that the requirements and wishes are similar and that requirements are weighted higher than wishes. Instead of having four requirements/wishes regarding real-time data, this is combined into one requirement that takes into account all four requirements/wishes (table 4.2). The same is done regarding takt time effects in table 4.3.

The requirement, *Easily be able to see a graph with the pressure over several cycles* from interviews with the machining department, ends up outside our scope as it is more about how and where the data is presented rather than how it is collected. So it is not something that will be included in the requirements specification.

Table 4.2: Merge 1 of Requirements and Wishes

The interviewee	The requirements/wishes from the interviewee
interview machining department	Wish: Real-time production data from sensors in the machining production
Interview assembly department	Wish: Real-time production data from sensors in the assembly line
Interview energy consumption case	Wish: Real-time data of energy consumption
Interview department of intelligent factories	Requirement: Can handle real-time production data from sensors in the production
Merged	**Requirement: Can handle real-time production data from sensors in the production.**

Table 4.3: Merge 2 of Requirements and Wishes

The interviewee	**The requirements/wishes from the interviewee**
Interview machining department	Requirement: Must not negatively affect the takt time on the machining line
Machining evaluation case factories	Requirement: Must not take time or disturb the machining production
Interview assembly department	Requirement: Must not negatively affect the takt time on the assembly line
Merged	**Requirement: Must not negatively affect the takt time in the production**

Requirements Specification for Technical Solutions

The requirements from the interviews with the stakeholders and the requirements from the evaluation cases are combined in the table presented below (see appendix C). In table 4.4 all the requirements are organized and given a shorten, for example, Requirement 1 becomes R1.

Table 4.4: Requirements Specification for Technical Solutions

Requirement	**Which stakeholder?**
R1: Can handle real-time production data from sensors in the production	Machining Department Assembly Department Department of Intelligent Factory
R2: Must not negatively affect the takt time in the production	Machining Department Assembly Department Department of Intelligent Factory
R3: Standard solution developed by another company and only needs to be adapted to Aurobay's production	Department of Intelligent Factory
R:4 The technical solution should not be limited to Siemens PLC system	Department of Intelligent Factory
R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution	Machining Department
R6: Automatically in real-time be able to collect alarm logs from PLC.	Assembly Department
R7: Be able to obtain energy consumption data from different machines	Simulations of Energy Consumption
R8:Should be able to handle the output current of 4 to 20 mA from the current sensor measuring 100 A	Simulations of Energy Consumption
R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.	IT-security Department
R10:The messages sent must be encrypted (excluding messages within industrial network)	IT-security Department
R11: The solution must contain authentication (excluding messages within the industrial network)	IT-security Department

4.2 Literature Study

In this section, research question 1 will be answered: *What technical solutions are available on the market that fulfills the requirements and wishes of the stakeholders?* The methods used are described in Chapter 3. The result will be prescribed in an evaluation matrix where all solutions are compared to the requirements that have been set.

From table 4.5, it is possible to conclude which of the technical solutions achieves the requirements in the requirement specification (table 4.4), which is the answer to RQ1. Table 4.5 first row shows that lists the technical solutions to be evaluated and the first column shows all the requirements that are evaluated. The cells are color-coded with green for yes, yellow for probably and not found, and red for no. This gives a clear overview of which solutions meet which requirements. An introduction to the technical solutions can be read in section 2.3. A deeper analysis of how the results in the table were conducted can be seen in Appendix B.

Table 4.5: Evaluating Technical Solutions Based on Requirements Specification

Requirement	OPC UA	MQTT	ExpertLogger	IXON Cloud IOT	Sparkplug	MachineMetrics Edge Hardware	ioLogik E1200 Series	s7-1200 OPC UA	Brownfield Connectivity
R1: Can handle real-time production data from sensors in the production	Y [53]	Y [13]	Y [7]	Y [17]	Y [20]	Y [48]	Y [34]	Y [12]	Y [63]
R2: Must not negatively affect the takt time in the production	-	-	Y [6]	P [38]	NF	Y [46]	Y [33]	Y [12]	Y [56]
R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production	Y [21]	Y [1]	Y* [6]	Y [38][16]	Y [28]	Y [47]	Y [33]	Y [21]	Y [57]
R:4 The technical solution should not be limited to Siemens PLC system	Y [21]	Y [40]	Y [6]	Y [38][16]	Y [26]	Y [47]	Y [33]	N [60]	Y [15]
R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution	-	-	Y [6]	Y [17]	Y [26]	Y [46]	Y [32]	Y [60]	Y [63]
R6: Automatically in real-time be able to collect alarm logs from PLC	NF	NF	NF	NF	NF	P [45]	NF	NF	NF
R7: Be able to obtain energy consumption data from different machines	-	-	Y [6]	Y [17]	Y [26]	Y [46]	Y [32]	Y [12]	Y [63]
R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A	-	-	Y [6]	Y [17]	Y [26]	Y [46]	Y [32]	Y [60]	Y [63]
R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.	Y [24]	Y [64]	Y* [6]	Y** [16]	Y** [64]	Y* [47]	Y* [33]	Y*	Y [56]
R10:The messages sent must be encrypted (excluding messages within the industrial network)	Y [24]	Y [64]	Y* [6]	Y** [16]	Y** [64]	Y* [47]	Y* [33]	Y*	Y [56]
R11: The solution must contain authentication (excluding messages within the industrial network)	Y [24]	Y [64]	Y* [6]	Y** [16]	Y** [64]	Y* [47]	Y* [33]	Y*	Y [56]

**The technical solution is based on the OPC UA protocol which is analyzed in the table and the analysis can be partly transferred to the technical solution.*
***The technical solution is based on the MQTT protocol which is analyzed in the table and the analysis can be partly transferred to the technical solution.*
Y - Yes.
N - No.
NF - Not found, a valid and reliable answer could not be found.
P - Probably, no reliable answer found, sources indicate a possible solution.

The requirements R1 and R3 handle requirements regarding collecting real-time data from sensors and that the solution should be developed by another company, these requirements are met by all the different technical solutions.

Requirement R2 on IXON Cloud IOT is set as P (probably) technical solution is connected directly to the PLC[38], there is a possibility that it affects the cycle time of the PLC program when it has to send data. To find out if it disturbs the takt time, a deeper investigation of the product and more knowledge of how the PLC processes data are required.

The requirement R4, the technical solutions should not be limited to Siemens PLC are met by all technical solutions except the *s7-1200 OPC UA*.

Requirements R5 and R8 are both regarding transferring data from an analog input of 4 to 20 mA. This requirement is met by all technical solutions except OPC UA and MQTT. This is challenging since OPC UA and MQTT are different protocols for data transmission and necessitate hardware to supplement it with the actual data acquisition solution. Hence, it is not feasible to credibly determine how the following requirements are affected: *R2, R5, R7,* and *R8.*

Requirement 6, *Automatically in real-time be able to collect alarm logs from PLC* was in some cases hard to evaluate. Aurobay's main supplier of PLC is made by Siemens and that is where the extraction of alarm logs should be done. The problem is that Siemens has difficulty in being able to clearly defining what is required to extract the alarm log from the PLC automatically in real time. This leads to the fact that it is difficult to check whether the requirement has been achieved because the requirement is difficult to define. To make sure that the requirement is achieved a test in reality for each unique technical solution needs to be done. Doing this is time and resource intensive and was not feasible in the project.

Regarding R6 MachineMetrics Edge Hardware, on the company's webpage, they state that it is possible to send and store alarms from the PLC to their server so that it is possible to monitor the alarms in real-time[45]. But since there is no information about this requirement, it cannot be ensured that it works at the case company.

The requirement R7 is about being able to collect energy consumption data, this is possible for all technical solutions except OPC UA and MQTT.

All requirements regarding IT-security (R9, R10, R11) are met by all the technical solutions that are evaluated in the test. All the technical solutions are based on either the protocol *OPC UA* or *MQTT* which meets the requirements set by the IT-security department.

Technical Solutions That Fulfill the Requirements

Below the technical solutions that guaranteed fulfill all the requirements if one ignores R6 (since it is not properly defined and hard to evaluate) are listed, which is the main takeaway from table 4.5. The technical solutions that may fulfill all the requirements if one sees *probably* and *not found* are ignored since they can't be guaranteed to fulfill the requirements.

- OPC UA
- MQTT
- ExpertLogger
- MachineMetrics Edge Hardware
- ioLogik E1200 Series
- Brownfield Connectivity

4.3 Recommend Technical Solutions

In this section, the final recommendation to the case company will be made, and an answer to RQ2 will be given. The evaluation of the technical solutions will be based on criteria. First, all technical solutions will be analyzed in each criterion and secondly, they will be compared to each other in a Pugh matrix.

In the Pugh matrices, the four technical solutions that have passed the requirement specification are evaluated. The protocols(OPC UA & MQTT) are not included in the matrix as it is the hardware solutions that are evaluated, but they are reflected through IT-security level criteria. The hardware includes the protocols.

Solution is Independent on PLC to Work
Brownfield connectivity has the possibility to extract data directly from sensors but also through the PLC[56]. MachineMetrics Edge Hardware also has the possibility to go through PLC or take the value directly from the sensor [46]. This also applies to ioLogik E1200 Series[33]. Expertlogger can't connect to the PLC and needs to be connected directly to the sensor[6].

Installation & Configuration
ExpertLogger mainly markets itself against: *environmental measurement technology, product testing, measurement data diagnosis, lab data acquisition, trials & tests* and *also energy optimization*[7]. This can indicate that it is not developed as an easy installation and configuration solution for production since this should have been mentioned if they see it as a market segment.

MachineMetrics Edge Hardware Plug & play adapters make data tag mapping and standardization unnecessary, allowing for universal data collection in PLCs that support open protocols [47]. This shows that it has a strong focus on Plug & play. On ioLogik E1200 Series and Brownfield Connectivity company websites, there is no documentation that indicates that the solution is plug & play, nor that it is a quick and simple installation process.

Stability of Company
Brownfield Connectivity is a product from Siemens. Siemens has 313,000 employees worldwide[58]. It is the next largest company in Germany when it comes to market capitalization, they have a market capitalization of 102 billion U.S. dollars[62]. This is a large and stable company.

ExpertLogger is developed by Delphin Technology AG. Delphin Technology AG was founded in 1980[4]. The company is based in Germany and it is hard to find information about the company's finances. No credible source was found, but it is claimed that they have a revenue of $6.2M[42]. On LinkedIn, they say they have 11-50 employees[5]. This indicates that it is a smaller company.

Machinemetrics is a relatively small company with about 70 employees and it was founded in 2014, the head office is in Northampton, USA. The company has an annual profit of 14.7M USD.[43]

MOXA, which sells the ioLogik E1200, was founded in 1987 and has over 1,000 employees. It is a well-established company that has been in the industry for over 35 years[50]

Product Maturity
Expertlogger was released in 2015, the product has been on the market for about 8 years and uses the technology that is relevant today[8]. Machinemetrics was founded in 2014 and they only work with data collection and platforms for data analyses. No source was found regarding when MachineMetrics Edge Hardware was released, it can't be earlier than 2014 since this is when the company was started.

A release date was not found for MOXA's iLogick E1200, however, updates of the firmware were found that were made in 2011, which indicates that the product was launched before 2011. This means that this product has been on the market for about 12 years.[51]

Siemens released Brownfield connectivity in 2019, this makes it a relatively new and unproven product that has not been implemented and tested for a long time at companies.[15]

It-Security Level
Compared to MQTT, OPC UA offers a more comprehensive security approach. It includes a dedicated security framework that encompasses user security, based on X.509, session security based on AAA, and transport security that relies on message encryption.[61]

The OPC UA versus MQTT is a relevant comparison since these protocols are used as a base in the different technical solutions. ExpertLogger, IoLogik E1200 Series, and MachineMetrics Edge Hardware are only using OPC UA [6][47][34]. Brownfield Connectivity on the other hand is utilizing both OPC UA and MQTT [56]. This shows that the solutions that have OPC UA as the protocol has a higher security standard.

Pugh matrices

The knowledge presented in this section is used to make the Pugh matrices shown below. The table is color-coded to get a better overview with "++" as dark green, "+" as light green, "=" as yellow, "-" as light red, and "–" being dark red. In the first iteration (table 4.6) MachineMetrics Edge Hardware gets the best result with a small margin compared to ioLogik E1200 Series, the MachineMetrics Edge Hardware, therefore, becomes the reference in the second iteration of the Pugh matrix (table 4.7).

Table 4.6: Pugh with IoLogik E1200 Series as Reference

Criteria's	Criteria rating	ioLogik E1200 Series (Reference)	MachineMetrics Edge Hardware	ExpertLogger	Brownfield Connectivity
Solution is Independent on PLC to Work	25%	0	=	- -	=
Installation & Configuration	15%	0	+ +	=	=
Stability of company	10%	0	-	- -	+
Product maturity	10%	0	-	- -	- -
It-Security level	40%	0	=	- -	- -
Sum of =		0	2	1	2
Sum of +		0	2	0	1
Sum of -		0	2	8	4
Weighted +			0,3	0	0,1
Weighted -			0,2	1,7	1
Rank		**2**	**1**	**4**	**3**

Table 4.7: Pugh with MachineMetrics Edge Hardware as Reference

Criteria's	Criteria rating	MachineMetrics Edge Hardware (Reference)	ioLogik E1200 Series	ExpertLogger	Brownfield Connectivity
Solution is Independent on PLC to Work	25%	0	=	- -	=
Installation & Configuration	15%	0	- -	- -	- -
Stability of company	10%	0	+	-	+ +
Product maturity	10%	0	+	-	- -
It-Security level	40%	0	=	- -	- -
Sum of =		0	2	0	1
Sum of +		0	2	0	2
Sum of -		0	2	8	6
Weighted +			0,2	0	0,2
Weighted -			0,3	1,8	1,3
Rank		**1**	**2**	**4**	**3**

Even when MachineMetrics Edge Hardware is used as a reference, it wins over the ioLogik E1200 Series by a small margin. The other two solutions perform significantly worse, although it can be seen that Brownfield Connectivity performs better than ExpertLogger.

4.4 Final Recommendation to the Case Company

Both the ioLogik E1200 Series and MachineMetrics Edge Hardware have made it through the requirements set by stakeholders. They have performed well in the further analysis of technical solutions. MachineMetrics Edge Hardware performed marginally better than the ioLogik E1200 Series. Our further recommendation to the company is to do small-scale tests where they try to implement both solutions in parallel in either a "lab environment" or directly towards the production line. This will generate a deeper understanding of the solutions and be able to guide companies in which system to potentially choose for their data collection in production.

5

Discussion

The discussion will be based around the research questions, section 5.1 will handle research question one, section 5.2 will handle research question two, and section 5.3 will focus on how the return rate affects sustainability.

5.1 Technical Solutions That Fulfills Requirement Specification

RQ1 - What technical solutions are available on the market that fulfills the requirements and wishes of the stakeholders?

The requirements from the it-security department could be called "hygiene requirements". They reflect the most important parts of IT security, but you could, for example, match all technical solutions against Aurobay's IT policy, IT time-consuming work that could exclude certain technical solutions. If one analyses the requirements in general, there may be indications that tougher requirements could have been used, for example, most of the technical solutions passed all the requirements. This could be because we only received the "basic requirements" from stakeholders, by "basic requirements" we refer here to the requirements that are seen as self-evident and a must-have for this type of technical solution. It is reasonable to assume that most players in the market meet customers' general basic requirements. The fact that stakeholders were not able to specify requirements that could be considered only found in the "premium technical solutions" could be because they do not use the product today and don't know what they want.

A problem that arose when the requirements were to be put together was that no one could help us define the requirements required for a technical solution to send alarm logs from the PLC. The problem may seem simple but is complex, one can simply say that different alarm codes are used in different places in the system. Siemens is the supplier of the PLC system that is used today and they had no clear directives. They stated that their solution, Brownfield connectivity, could send most types of alarm logs. Indications were also found regarding MachineMetrics Edge Hardware being able to send the alarm log, however, this was difficult to guarantee as the requirement from the PLC was ambiguous.

5.2 Evaluate Chosen Technical Solutions

RQ2 - How to evaluate the chosen technical solutions based on the requirement specification?

Depending on how the criteria are chosen and how they are weighted against each other in the Pugh matrix, the end result can vary, it can therefore give a different end result if other criteria are chosen and other parameters are weighted in a different way. The analysis that is done is based on what we, together with our supervisor, value as important criteria, but if another person with different experiences does the same analysis, it may end up with a different result.

To further evaluate the technical solutions, practical tests can be carried out in a lab environment to find additional weaknesses or strengths with the various solutions, and to ensure that they work in a way that makes it possible to implement in the case company's production. After these tests, it can be established whether a technical solution works in practice, which we have not had the time or resources to do

5.3 Sustainability

An aspect that is worth noting when it comes to sustainability is how much of the data that is collected is actually used, there is a lot of focus on collecting data so that it could be used to improve production, but if the data is not used both environmental and economic resources has been used unnecessarily. It is therefore important that there is a clear purpose for what the data will be used, otherwise, there is a chance that resources are used to collect data that will never be used.

However, with the help of data collection and analysis of that data, it is possible to improve the sustainability of the production. By maximizing the utilization of machines and tools so that they are not idle or that the tools are replaced before their entire useful life is used up, it is possible to get better durability without actually making any major changes in production [39].

It is possible to collect both valuable and non-valuable data with the technical solution that was analyzed, it is up to the user to make smart decisions about which data to collect, it is the user who must utilize the tools in a rational and efficient way.

5.4 Limitations

A source that generates uncertainty is the fact that the case company is large with approximately 1300 employees in the factory that was analyzed in this report, this led to a selection among the production lines to limit the number of stakeholders and interviews. There may be other requirements that we have not encountered. Another method of solving the problem could have given a broader analysis. However, it could likely have taken more resources to do it with another broader method.

A typical problem with this type of analysis is that they become outdated relatively quickly. Analyzing technical solutions in a field that is upcoming means that the solutions quickly change and improve. This means that within a few years, the analysis that has been done will be outdated since the solutions and software that has analyzed have been updated and improved several times. The method of tackling a multidisciplinary problem is relevant and will remain so. The method is written generically and could potentially be used to solve other similar problems. This phenomenon shows that the validity of the result is most valid at its first publication; however, its validity gradually decreases over time.

Collecting data in production is a large commercial area and there is a large number of players in the market. It is unlikely that all technical solutions on the market have been found. But a range of technical solutions that use different techniques to collect data have been found.

Relying solely on the information provided by companies regarding their technical solutions can be risky for evaluating if they meet requirements. Ideally, the technical solutions would just be evaluated based on scientific articles. Scientific articles are considered more credible than the information presented on a company's website or technical specifications. Companies have an incentive to promote the positive aspects of their products, which can lead to incomplete or misleading information being presented. Greater transparency and disclosure from companies are needed to address these risks. If one were to only analyze solutions that are analyzed in articles, one would have had to focus the analysis on the largest companies and many small and potentially good solutions would have been overlooked simply because they are not established enough to have received academic analyses. However, this risks the validity of the result as the source of information can be seen as biased.

6
Conclusion

The project was carried out in three stages, the first stage was to identify how the data collection is done today and who are the stakeholders for the new technical solution. The second step was to identify which solutions were on the market that fulfilled the requirements that the case company's internal stakeholders placed on the technical solution. The third and last step was to evaluate the solutions that met all the requirements and finally give a recommendation.

RQ1 - What technical solutions are available on the market that fulfills the requirements and wishes of the stakeholders?
Seven stakeholders were identified, analyzed, and interviewed, the primary stakeholders were: *Assembly line* and *Machining line*. The secondary stakeholders were: *Department of Intelligent factory*, *Unlocking Plant Floor Data*, *Software developers – PLC*, and *IT security*. The stakeholders gave recommendations for 3 evaluation cases: *Machining evaluation case*, *Assembly evaluation case*, and *Energy simulation evaluation case*. The interviews and the evaluation cases resulted in 11 requirements:

1. Can handle real-time production data from sensors in the production
2. Must not negatively affect the takt time in the production
3. Standard solution developed by another company and only needs to be adapted to Aurobay's production
4. The technical solution should not be limited to Siemens PLC system
5. Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
6. Automatically in real-time be able to collect alarm logs from PLC
7. Be able to obtain energy consumption data from different machines
8. Should be able to handle the output current of 4 to 20 mA from the current sensor measuring 100 A
9. DMZ proxy: is a zone located between the local network of an organization and the world beyond it
10. The messages sent must be encrypted (excluding messages within industrial network)
11. The solution must contain authentication (excluding messages within the industrial network)

In total nine technical solutions were analyzed through a literature study to evaluate if they meet the requirements of the stakeholders. In total six of the nine technical solutions meet the requirements and are therefore the answer to RQ2, these solutions are listed below:

- OPC UA
- MQTT
- ExpertLogger
- MachineMetrics Edge Hardware
- ioLogik E1200 Series
- Brownfield Connectivity

RQ2 - How to evaluate the chosen technical solutions based on the requirement specification?
The evaluation of the six technical solutions that meet the requirements was done using a Pugh matrix, the criteria and weighting for evaluation were:

1. 40%: It-Security level
2. 25%: The solution is not dependent on PLC to work
3. 15%: Installation & Configuration
4. 10%: Stability of the company
5. 10%: Product maturity

The Pugh matrix underwent two iterations, resulting in the answer to RQ2. The outcome was that MachineMetrics Edge Hardware proved to be marginally superior to the ioLogik E1200 Series, making it one of the two most optimal solutions.

With these two technical solutions, the case company will have the capability to acquire real-time data and collect data with the stakeholders' specific requirements. The technical solutions have a process where data is both collected and transferred according to the requirements of the case company. With this, the aim of the project is fulfilled.

External Influence:

- IoT is driven by four primary drivers, two of which are Sensors and Big data[22]. This project has provided a method where a company can further develop its data acquisition system to collect and transfer sensor data in real-time, which if done correctly, can lead to IoT. The method can be seen as a step guide to how companies can further develop their data collection.
- By streamlining production, it is possible to achieve better sustainability both financially and environmentally [39]. Losses can be reduced and the degree of utilization of both machines and tools can be improved, which creates less waste, for example, energy, material, time etc.
- This thesis has identified weaknesses that may exist in a production system that prevent the use of Industry 4.0 technologies. By closing the gaps in the data collection that exist at the case company, opportunities to use these technologies to a greater extent will emerge. This could be helpful for others as they can learn what gaps may exist in production companies and how these gaps can be identified in order to take steps toward Industry 4.0.

Recommendation for future work

The next step would be to further evaluate the two technical solutions to each other through lab tests or small-scale tests in production. This is to ensure that the theory matches the reality of the case company's production system. Since this area is in constant change and the technical solutions on the market continually develop and new technical solutions join the market, it is vital to understand that this study needs to be updated within a few years in order to stay relevant.

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A

Identification & Analysis of Primary and Secondary Stakeholders

A.1 Stakeholder Identification

All names of stakeholders are codenames with the exception of the supervisor from the case company. The first set of stakeholders was identified with the help of brainstorming together with Helene Askros, Department of intelligent factory. She is the main stakeholder and has a lot of knowledge about the organization. The stakeholders from the brainstorming session that she recommended we start contacting are the following:

- *Project called: Unlocking Plant Floor Data* - represented by Walle,
- Assembly line - represented by Lars, Process Owner Propulsion Production

When talking to Lars at the assembly line he advised that Greger and Frej in department Machining VCES could be a good complement to the assembly line in the project. Helene Askros recommended including Samuel and Filip Software developers in PLC at Intelligent factory as stakeholders since they are working with the production communication systems today. She also recommended including the simulation engineer Rasmus who, among other things, works to simulate energy consumption in the factory, he has requested data to validate his simulations. She, in addition to that, also recommended contacting Noah who works as a security specialist in the IT-department.

- Machining - represented by Greger, Superintendent Cylinder head Machining and Frej, Manager Shop Engineering Machining
- Software developers – PLC - represented by Samuel and Filip at – Intelligent factory
- Energy consumption simulations - represented by Rasmus at Global Line and Equipment
- IT security - represented by Noah at the IT-department.

When interviewing Samuel and Filip they explained that they work with managing the software of the VDcom_v2 system and coordinate the hardware but that the maintenance department is responsible for the hardware.

Throughout the stakeholder identification, seven different stakeholders were identified:

Table A.1: Identified Stakeholders

Stakeholders
Department of Intelligent factory
Unlocking Plant Floor Data
Assembly line
Machining line
Software developers – PLC
Energy consumption simulation
IT security

A.2 Analysis of Primary and Secondary Stakeholders

A.2.1 Primary stakeholders

Department of Intelligent Factory
The Department of Intelligent factory has initiated this master's thesis since they have identified a need for an extended collection of real-time data. A future goal for the department is to be able to collect data where there are gaps today. The result can become a basis for future projects, therefore they are a primary stakeholder in this project. As a result of the project being initiated by the department, it will follow their interests. The impact of the project is positive since they have requested the analyses that are carried out in the project. The priority of the stakeholder is high since they are the main customer of the thesis.

Machining
They collect a lot of the data, and some of this is done manually in a time-consuming way. They will be affected to a large extent by the project's results as it can facilitate their work, therefore they are a primary stakeholder. They would appreciate some more data for condition-based maintenance, therefore the interest of the department and the goals of this project align. The impact of the project is that their work tasks would be made easier if more of the data were collected automatically, this would help them to get overviews faster, today the manual data is collected once a week.

Assembly line
The impact the project could have on the assembly line is the same as on the machining line. Collecting data automatically will directly affect their work, therefore they are seen as a primary stakeholder

In assembly, much of the work is done manually, making it a challenge to collect data without disturbing the workers. However, there is a need to be able to collect certain data, an example is alarm logs that today have to be collected manually from the PLC with a USB. Collecting the alarm logs automatically would ease the work to put together KPIs, therefor the interest aligns with the project.

A.2.2 Secondary Stakeholders

Unlocking Plant Floor Data
The *Unlocking Plant Floor Data* project is seen as a secondary stakeholder because they do not work directly with the data collected by the new technical solution. They just make sure that the data that exists is available to the workers in the factory.

Walle expresses it clearly, he is positive about expanded data collection since it will be an enabler for his *Unlocking Plant Floor Data* project. Therefore his interests are aligned with this master's thesis. The project will require large amounts of data, which the technical solution of this project will generate. The impact of the project will be positive since he is not affected by the workload to gather the data.

Software Developers – PLC
The software developers are secondary stakeholders as they do not have direct contact with the project, however, they have a lot of knowledge about the current system for data collection.

Their interest in the project is neutral since it should not affect their work. The impact should also be low since the new technical solution should work in parallel with the existing solution. The priority of the stakeholder is set as low since they are natural.

Energy Consumption Simulation
To further develop the energy consumption simulations a faster and more reliable data flow from the machines is requested. The interest is to get more valid data to be able to satisfy his internal customers at Aurobay. The impact of the project is that if they get a better dataset to work with they can deliver better simulations.

IT Security
They are seen as a secondary stakeholder because they only make requirements but really have no opinion on what the system does. They remind of governments (which are typically seen as secondary[11]), they decide on rules but do not care what one does as long as one follows the rules. Their interest in the project is neutral as it is not expected to affect their work, and the level of impact is anticipated to be low since they are not invested in the outcome. However, this is based on the fact that the rules regarding IT security are followed.

B

Literature Study to Evaluate Technical Solutions

B.1 OPC UA

OPC UA stands for Open Platform Communications Unified Architecture. The OPC Foundation developed the OPC UA protocol as an advanced, platform-independent, service-oriented architecture that offers capabilities beyond the basics, including discovery, address space, data modeling, and security. OPC UA uses a standard client-server mechanism, with the server featuring an information model that organizes data in a structured format.[67]

The OPC protocol has established itself as the standard for ensuring secure and dependable data exchange in industrial automation and various other sectors. It is platform-agnostic and has a seamless information flow among devices provided by different manufacturers. The OPC Foundation is responsible for formulating and maintaining this protocol. The OPC standard is a suite of specifications devised by industrial vendors, end-users, and software developers. These specifications outline the interface linking clients and servers, as well as servers and other servers, which encompasses access to real-time data, event, and alarm monitoring, retrieval of historical data, and other applications.[25]

Searching in Scopus with the term *OPC UA* resulted in 4 010 documents and Google Scholar gave 15 900 results.

Iteration 1 of snowballing
The starting papers for snowballing were chosen to:

- Ontology Implementation of OPC UA and Automation ML: A Review [21]
- Assessing the Security of OPC UA Deployments[30]

OPC UA is a Standardized information model [21]. This makes information shows that the requirements below are met:

- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production.
- R:4 The technical solution should not be limited to Siemens PLC system.

OPC UA provides various options for client authentication, such as anonymous access, username, and password combination, certificate-based authentication, or authentication token.[30]

This information indicates that the following requirements have been satisfied:

- R11: The solution must contain authentication (excluding messages within the industrial network)

Iteration 2 of snowballing
By forward snowballing the paper *A Service-Oriented Real-Time communication Scheme for AUTOSAR Adaptive Using OPC UA and Time-Sensitive Networking* the paper *Ontology Implementation of OPC UA and Automation ML: A Review* was found. The information found from the second iteration was that: OPC UA technology enables real-time communication patterns [53].

This information shows that the following requirements have been met:

- R1: Can handle real-time production data from sensors in the production.

After this, the second part of the literature method was used, finding technical specifications from companies. The article *Leveraging OPC-UA PubSub as a DMZ Gateway* was found on OPC Foundation Website [24].

OPC UA PubSub serves can be used as an application by acting as a DMZ Gateway between two distinct networks. This allows for secure exchange of data between two networks. Additionally, OPC UA PubSub incorporates a standardized SHA 256 encryption algorithm that facilitates the transfer of plant data to the cloud.[24]

This information demonstrates that the following requirements have been fulfilled:

- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network).

When it comes to some of the requirements there are difficulties to determine the impact of OPC UA as it is a protocol for sending data and requires hardware that complements it with the actual data collection solution, it is therefore not possible to on a credible say how the requirements below are affected.

- R2: Must not negatively affect the takt time in the production.
- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution.
- R7: Be able to obtain energy consumption data from different machines.
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A.

B.2 MQTT - Message Queuing Telemetry Transport

MQTT is an open message protocol that positions itself as an extremely lightweight publish/subscribe machine-to-machine and Internet of Things connectivity protocol. It prioritizes a small code footprint and low network bandwidth usage while being capable of handling high latency or poor network connections, making it ideal for communication between sensors via satellite link. Since 2013, MQTT has been standardized by the Organization for the Advancement of Structured Information Standards (OASIS) as the protocol for the Internet of Things. In MQTT, an MQTT-Server, also known as a broker, stores the complete data of all communication partners. Small devices report data to the broker, eliminating the need to store the data themselves.[40]

Searching in Scopus with the term *MQTT* resulted in 9 440 documents and Google Scholar gave 55 300 results.

Iteration 1 of snowballing
The starting papers for snowballing were chosen to:

- IoT real time data acquisition using MQTT protocol [13]
- OPC UA versus ROS, DDS, and MQTT: Performance Evaluation of Industry 4.0 Protocols [40]
- MQTT protocol employing IOT based home safety system with ABE encryption[64]

The utilization of MQTT is a viable choice for real-time data acquisition[13]. This information makes that the following requirement has been fulfilled:

- R1: Can handle real-time production data from sensors in the production.

The Organization for the Advancement of Structured Information Standards (OASIS) has standardized MQTT as the protocol for the Internet of Things (IoT) [40]. Since it is an information standard it is not limited to Siemens, therefore the requirement below is met.

- R:4 The technical solution should not be limited to Siemens PLC system.

MQTT is deployable in a demilitarized zone (DMZ) and includes authentication features. Additionally, it encrypts message payloads using AES (Advanced Encryption System), and the AES key is encrypted through ABE(Attribute-Based Encryption) to ensure the payload and ciphertext sizes remain the same.[64]
The fulfillment of the following requirement is evidenced by this information:

This information is evidence that the following requirement is fulfilled:

- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network).
- R11: The solution must contain authentication (excluding messages within the industrial network).

Iteration 2 of snowballing
First, backward snowballing was used to gain new information regarding the requirements that couldn't be answered with the starting papers. This did not generate any new answers to the requirement specification. Second, forward snowballing was used which generated the paper *Energy Efficient and Secured MQTT Protocol us-*

ing IoT[1] since it had cited the paper *IoT real time data acquisition using MQTT protocol*.
From the second iteration, it was discovered that: One of the lightweight standard communication protocols is MQTT [1]. This fulfills the criteria:

- R3: standard solution developed by another company and only needs to be adapted to Aurobay's production.

Regarding some of the requirements, it is challenging to assess the impact of MQTT as it is a protocol for data transmission and necessitates hardware to supplement it with the actual data acquisition solution. Hence, it is not feasible to credibly determine how the following requirements are affected.

- R2: Must not negatively affect the takt time in the production
- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
- R7: Be able to obtain energy consumption data from different machines
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A

B.3 ExpertLogger

There are no articles about ExpertLogger on either Google Scholar or Scopus, therefore the analysis had to be based on technical specifications and the manufacturer's website.
Accurate measurement data can be acquired, stored independently, and transmitted to the internet or a PC for evaluation using USB, LAN, WLAN, or LTE with MQTT. When using WWAN (wireless wide area network), data can be accessed in real-time.[7]

This information shows that the technical solution met the requirement below:

- R1: Can handle real-time production data from sensors in the production

The device operates independently from the PLC and relies on its own input through sensors. It is a solution designed using OPC UA. The current measurement range for input is from 0 to 20 mA. [6]
Since the system does not rely on the PLC and measures the value directly from the sensors, the system becomes parallel to the current system and will thus not affect the takt time. This information can confirm that the following requirements are met:

- R2: Must not negatively affect the takt time in the production
- R:4 The technical solution should not be limited to Siemens PLC system
- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
- R7: Be able to obtain energy consumption data from different machines
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A

Since ExpertLogger is based on OPC UA, as analyzed in section B.1, the analysis can be partly transferred and the requirements listed below can be seen as met:

- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production
- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network)
- R11: The solution must contain authentication (excluding messages within the industrial network)

B.4 IXON Cloud IOT

IXON is a cloud-based industrial automation and IIoT platform that provides a comprehensive solution for remote access, monitoring, and data collection. One of the features of the IXON platform is its ability to collect and analyze data from various industrial devices and machines.[38][17]

At Scopus, no articles that included *IXON*, *Cloud* and *IOT* was found. Google Scholar on the other hand generated 62 results, however, all of them were out of context or only mentioned the technical solution so briefly that no conclusions could be drawn regarding the requirements specification. As a consequence of this, snowballing literature study cannot be applied. This resulted in the study needing to rely on technical specifications and information provided on the manufacturer's website.

The IXON Cloud IOT is capable of generating and transferring data in real-time. When combined with a PLC, IXON has the capability to manage an output current range of 4 to 20mA. Typically, machines are equipped with a PLC, and this enables the IXON solution to gather data from multiple machines simultaneously.[17]

This confirms the following requirements:

- R1: Can handle real-time production data from sensors in the production.
- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution.
- R7: Be able to obtain energy consumption data from different machines.
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A.

The solution is connected to the PLC/HMI, there are indications that it does not interfere with the cycle time, but it cannot be ensured without further testing. [16] IXON Cloud IOT has a standard setup procedure to connect to a PLC[38]. The IXON Cloud IOT has the possibility to gather data from PLC/HMI, IPC, robot, or IP camera of any brand [16]. This shows that the following requirement is met:

- The requirement is probably met, R2: Must not negatively affect the takt time in the production

- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production.
- R:4 The technical solution should not be limited to Siemens PLC system.

The analysis conducted in section B.2 can be partially applicable to IXON Cloud IOT, as it is built on MQTT [13]. Thus, the following requirements can be considered met:

- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network).
- R11: The solution must contain authentication (excluding messages within the industrial network).

B.5 Sparkplug

There are no articles about Sparkplug's technical solutions on either Google Scholar or Scopus, however just the keyword: Sparkplug gives 21 600 hits on Google Scholar since it is a component used in engines, but when adding more relevant keywords no articles were found. Therefore the analysis had to be based on technical specifications and the manufacturer's website.

Sparkplug is an open-source software specification that provides MQTT clients with a framework to seamlessly integrate data originating from their applications, sensors, devices, and gateways into the MQTT Infrastructure. The utilization of SparkPlug facilitates the incorporation of data from various sources into the MQTT infrastructure in a consistent manner.[26]

Sparkplug is capable of enabling real-time SCADA/Control HMI solutions [20]. Sparkplug is an open-source specification, which means that it is a publicly available and modifiable set of guidelines and standards for designing and implementing industrial IoT systems[28].

This shows that:

- R1: Can handle real-time production data from sensors in the production
- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production

Sparkplug is versatile enough to be implemented on various edge devices, including those with a PLC, enabling them to handle output currents ranging from 4 to 20mA if there is a PLC in between. By combining Sparkplug with a PLC, it becomes possible to obtain energy consumption data from different machines(if they have a PLC), making it an effective solution for industrial settings.[26]

This is evidence that the following requirements are met:

- R:4 The technical solution should not be limited to Siemens PLC system
- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
- R7: Be able to obtain energy consumption data from different machines
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A

Sparkplug is based on on MQTT [27]. This makes section B.2 valid which shows that the following requirements are met:

- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network).
- R11: The solution must contain authentication (excluding messages within the industrial network).

B.6 MachineMetrics Edge Hardware

The MachineMetrics Edge Platform presents an easily scalable answer for manufacturers, which they can self-install to effortlessly gather data from any machinery and promptly obtain valuable machine insights. The platform supports universal data collection through Plug-and-Play functionality for PLCs that use open protocols and can take i/O directly. [47]

At neither Google Scholar nor Scopus any articles were found when using the term *MachineMetrics Edge Hardware*, therefore the literature was gathered from the company's webpage.
The MachineMetrics Edge Platform has the capability to transmit data in real-time using both Ethernet and wireless technologies[48].

The MachineMetrics Edge Hardware is a simple and Plug-and-Play device that enables universal data collection from PLCs. It supports various open protocols such as MTConnect, OPC-UA, and Modbus, as well as proprietary connectors for PLCs from leading manufacturers including Fanuc, Mitsubishi, Citizen, Haas, Heidenhain, and Siemens Sinumerik.[47]
This together with the information in section B.1 is evidence that the following requirements have been met:

- R1: Can handle real-time production data from sensors in the production
- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production
- R:4 The technical solution should not be limited to Siemens PLC system
- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network)

- R11: The solution must contain authentication (excluding messages within the industrial network)

The MachineMetrics Edge Hardware can establish connections with both PLCs and I/O devices, enabling it to bypass the PLC and establish a direct connection directly with the sensors. [46]

This makes the possibility to meet the following requirements:
- R2: Must not negatively affect the takt time in the production
- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
- R7: Be able to obtain energy consumption data from different machines
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A

There is a possibility to extract alarm logs with MachineMetrics Edge Hardware[45]. However, there are some limitations with the solution that needs to be controlled via testing. So the following requirement is probably met:

- R6: Automatically in real-time be able to collect alarm logs from PLC

B.7 ioLogik E1200 Series

With support for commonly used protocols (including OPC UA) for retrieving I/O data, the ioLogik E1200 Series is capable of handling a diverse range of applications. This series retrieves I/O data and converts it into OPC UA protocol, enabling easy and seamless connectivity for data applications.[32]

The ioLogik E1200 Series utilizes the OPC UA, the latest generation OPC standard (IEC 62541), to offer a robust, secure, and dependable framework for accessing real-time and historical data[34]. Nevertheless, the ioLogik is a standard solution that can support other standard protocols as well [33].
The solution doesn't have to be connected to the PLC [33]. This makes it not effecting the PLC and its impact in the takt time. The ioLogik system is not dependent on PLCs and can transmit data directly to a SCADA system or computer[33]. The system's foundation relies on OPC UA[33]. The OPC UA is analyzed in section B.1. All this combined shows that the following requirements are met.
- R1: Can handle real-time production data from sensors in the production
- R2: Must not negatively affect the takt time in the production
- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production
- R:4 The technical solution should not be limited to Siemens PLC system
- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network)

- R11: The solution must contain authentication (excluding messages within the industrial network)

The I/O functionality of ioLogik is designed to accommodate input from sensors that measure both voltage and current. The solution can be used to collect and transfer data from different machines.[32]
This shows that the following requirements are followed:

- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
- R7: Be able to obtain energy consumption data from different machines
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A

B.8 s7-1200 OPC UA

In this technical solution, the OPC UA is combined with a SIMATIC S7-1200 controller by Siemens. These controllers are compact automation solutions that offer extended communication options and integrated technology functions. They are highly flexible and efficient, suitable for automating tasks in the lower to medium performance range. Additionally, they come equipped with a wide range of technological functions, integrated communication capabilities, and a space-saving design.[59]

The communication between the production area and the web platform in the S7-1200 OPC UA solution takes between 2 and 10 milliseconds in both directions. On average, it takes 6 milliseconds to transmit data from the PLC to the gateway. [12]
There is also an ability to connect multiple devices and production machines enabling process monitoring through a communication network linking the Siemens IOT2040 Intelligent Gateway and the PLC S7-1200. The IOT2040 Gateway serves as an industrial gateway, gathering, processing, and transmitting production data to the Freeboard platform.[12]
It is also verified that OPC UA is a standardized information model.[21]
The following requirements have therefore been met:

- R1: Can handle real-time production data from sensors in the production
- R2: Must not negatively affect the takt time in the production
- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production
- R7: Be able to obtain energy consumption data from different machines

Since the S7-1200 is a Siemens PLC the following requirement is not followed[60]:

- R:4 The technical solution should not be limited to the Siemens PLC system

The solution can handle an analog input between 0-20mA[60]. The system is based on OPC UA which is analyzed in section B.1.
Consequently, the following requirements have been fulfilled:

- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
- R8:Should be able to handle the output current of 4 to 20mA from the current sensor measuring 100 A
- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network)
- R11: The solution must contain authentication (excluding messages within the industrial network)

B.9 Brownfield Connectivity

When searches are made on Brownfield connectivity on google scholar, four results were generated that were not about the technical solution. A search on Scopus yielded 38 results that were not related to the technical solution.

This is probably because this is a relatively new solution that has not started to be used in academics yet. The term *brownfield* is used to describe production systems, hence a number of search results are obtained. The information found is therefore the company's website or from articles on Google.

In the context of Industry 4.0, factories that rely on legacy machines often encounter the challenge of obtaining real-time data for visibility and insights. Brownfield Connectivity addresses this issue by enabling companies to extract data directly from PLCs, screens, or installed sensors, and transmit it using open-source communication protocols [63]. This shows that the following requirements are met:

- R1: Can handle real-time production data from sensors in the production
- R2: Must not negatively affect the takt time in the production
- R5:Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution
- R7: Be able to obtain energy consumption data from different machines
- R8:Should be able to handle the output current of 4 to 20mA from the current

Brownfield Connectivity is a standardized technical solution that has been developed by Siemens[57]. Users have the ability to connect both Sinumerik CNCs and controllers, as well as automation solutions from third-party providers, to higher-level networks.[15] This information generates the answer to the following requirements:

- R:3 standard solution developed by another company and only needs to be adapted to Aurobay's production
- R:4 The technical solution should not be limited to the Siemens PLC system

Brownfield Connectivity can be based on both OPC UA and MQTT[56]. This is analyzed in section B.1 & B.2 which shows that the solution met the same requirements with both protocols. Further analysis is done with OPC UA as the main protocol. The requirements met are shown below:

- R9: DMZ proxy: is a zone located between the local network of an organization and the world beyond it.
- R10:The messages sent must be encrypted (excluding messages within the industrial network)
- R11: The solution must contain authentication (excluding messages within the industrial network)

C

Interview with Stakeholders and Evaluation Cases

C.1 Interview with Department of Intelligent Factory

The department of intelligent factory is represented by Helene Askros. An interview was held with her and was based on the questions formulated in section 3.1.4. Relating to question 2 (*What do you feel is the biggest problem with Aurobay's data collection today?)* she expressed the need for real-time data. At the department of intelligent factory they are working on how to develop the production and an important parameter to be able to develop production towards for example *condition-based maintenance* and *industry 4.0* is that one has real-time data.

In the matter of question 4 (*Do you have any other requirements or wishes regarding the data collection?*) Askros explicitly stated that the system must not have any unfavorable impact on production takt time, and emphasized that the proposed technical solution should be considered as a complement to VDcom_v2. It is also important that the new technical solution is a standard solution developed by another company and only needs to be adapted to Aurobay's production. The technical solution should not be limited to just Siemens PLC-system, it should work with other brands as well.

Requirements from interviews with Intelligent factory

- Requirement: The technical solution should handle real-time data.
- Requirement: The system must not have any unfavorable impact on production.
- Requirement: Standard solution developed by another company and only needs to be adapted to Aurobay's production
- Requirement: The technical solution should not be limited to Simens PLC system

C.2 Interview with Machining Department

The interview was held with Greger, Superintendent Cylinder head Machining, and Frej, Manager Shop Engineering Machining, who represent the machining department. The interview was based on the questions stated in section 3.1.4. The summarization of the meeting was that operators could benefit from having access to real-time pressure and temperature data, as it would streamline their tasks. By generating a graph that displays pressure or temperature fluctuations over the most recent cycles, operators could make more informed decisions based on the data. Today, a lot of data is logged, but it is unsynced and difficult to access. Therefore a lot of manual work is required to collect and sync the data.

One wish is to get the data in real-time in order to be able to use it for pulse meetings in order to more quickly detect and remedy problems in production. They are also adamant that any changes must not impact the cycle time or hinder production in any negative manner. The interview could be compiled into the following requirements:

Requirements from interviews with machining department

- Wish: Real-time production data from sensors in the machining production
- Requirement: Must not negatively affect the takt time on the machining line.
- The technical solution should not be limited to Siemens PLC-system

In the interview, they also recommended contacting Frans, Line technician in the processing line of the cylinder heads to identify and create an evaluation case concerning the washing of components.

C.3 Interview with Assembly Department

The interview was held with Lars, Process Owner Propulsion Production, who represents the assembly line. The interview was based on the questions stated in section 3.1.4. The problems with data and data collection turned out to be similar to the problems of the machining department, which were addressed in section C.2. The problem was similar in that the data was out of sync, need to be collected manually, and was difficult to access. Additionally, obtaining real-time data to guide their operators proved to be challenging. Another similarity was that the data collection must not negatively affect running production.

Lars also addressed the problem of conducting alarm logs, the problem is that they need to manually the data via USB at the machine, this is done once a week, and he wants this to happen automatically in real-time.

Requirements from interviews with assembly department

- Wish: Real-time production data from sensors in the assembly line
- Requirement: Must not negatively affect the takt time on the assembly line.
- Requirement: Automatically in real-time be able to collect alarm logs from PLC.

He addressed an evaluation case regarding collecting alarm history from machines.

C.4 Interview with Energy Simulation Engineers

Representing the stakeholder, in this evaluation case, is Rasmus, he has identified an information gap regarding the consumption of individual equipment and machines. The case was recommended by Helene Askros, Section C.1, Since she works with data collection, she saw that Rasmus lacks data to make simulations based on reliable data.

First, the interview questions from section 3.1.4 were asked to Rasmus. The conclusion of the interview was that they don't have any automatically logged data regarding energy consumption, when he needs energy data for simulations he needs to request an electrician to go and measure for some hours and manually collect the data. When it comes to for example *average time between failures* and *mean time to repair* he uses static data that is based on observations. He wishes to have data that is based on statistics from collected data from production.

The biggest problem with the way of working today is that there is no automatic data collection in energy consumption and that one needs to chase other people to get the data. He also says that how the data is collected does not affect him, because he will only use the data that is collected and stored in a database, he has no opinion about how it ends up there. He does have one wish regarding the data collection: he wants the data to be real-time. He says, however, that it would be enough for the data to be published in the database 24 hours after it is logged in the production, if you get it down to 10 minutes from production to the database, then it is really good.

Requirements from interviews with the stakeholder Simulations of energy consumption

- Requirement: Be able to obtain energy consumption data from different machines
- Wish: Real-time data on energy consumption

He also recommends contacting Julius, Energy optimizer, to get a more concrete understanding of how to measure and log energy data.

C.5 Interview with It-security

A meeting was held with the interview questions from section 3.1.4, however questions 1,2, and 5 were left out since It-security does not use production data. When discussing questions 3(*what consequences must the data collection process not have on your department?*) and 4(*do you have any other requirements or wishes regarding the data collection?*) with Noah he explained Aurobay's general IT-security philosophy, it is shown in figure C.1.

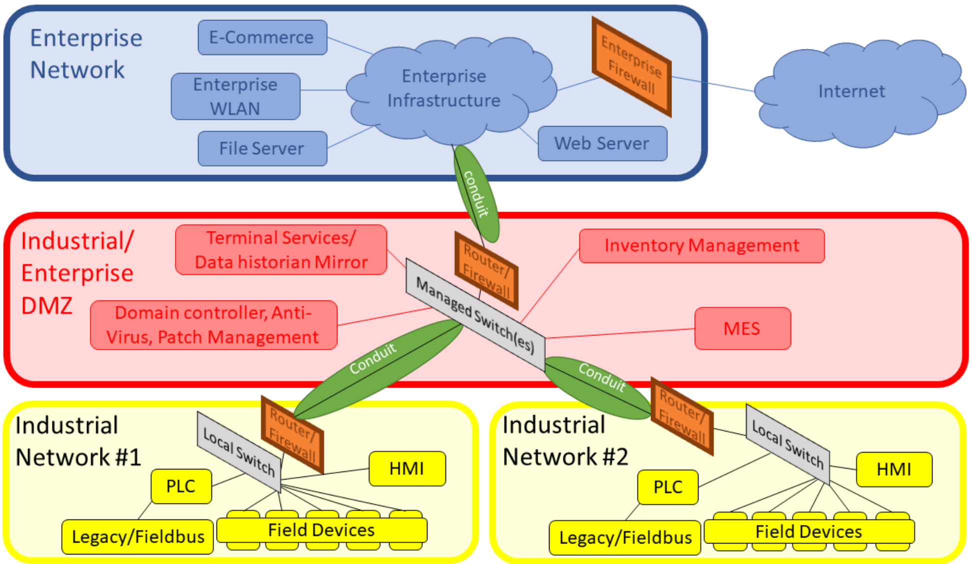

Figure C.1: Overaview of It Security

From a security perspective, there are three requirements for the solution.

Requirements from interviews with IT-security department

- DMZ proxy: is a zone located between the local network of an organization and the world beyond it. It is utilized for the purpose of increasing computer security.
- The messages sent must be encrypted (excluding messages within the industrial network)
- The solution must contain authentication (excluding messages within the industrial network)

C.6 Interview with Software Developers – PLC

The PLC developers are working with the current system but are not using the data that it produces, therefor questions 1 (*What kind of data could facilitate your workload?*) and 5 (*Do you have any suggestions on specific evaluation cases that could be good for evaluating the technical solution?*) where left out.

Regarding what the biggest problem with Aurobay's data collection is they state that since they use a telegram-based solution for data collection they cant do continuous data or images which is sometimes requested. The telegrams are also limited to 8000 bite each, nevertheless, if one has something bigger than 8000 bites, it can be split into several telegrams and then the receiver need to arrange the data, this is however complicated and impractical.

Another problem that they also mention with data collection today is the potential security risk associated with handling data via USB between machines and computers. There is a risk of viruses being spread via the USB used to retrieve information from various devices. Additionally, it is not possible to guarantee that the data does not spread outside the company.

On the subject of *What consequences must the data collection process not have on your department?* and *Do you have any other requirements or wishes regarding the data collection?* they had nothing to add.

C.7 Machining Evaluation Case

In the interview, they also recommended contacting Frans, Line technician in the processing line of the cylinder heads to identify and create an evaluation case concerning the washing of components. This was done with the Gemba method from section 3.1.5.

The steps in figure 2.1 (*Define the purpose of the Gemba visit*) was employed:

- Step 1: The purpose of the Gemba was to find a sensor on the machining line that could help the operators if the data was stored.
- Step 2: A meeting was planned in advance to give Frans the opportunity to prepare and inform operators.
- Step 3 & 4: We meet up with Frans and a senor operator to introduce ourselves and the project that is carried out.
- The results from Step 5 & 6 is explained and carried out below.

Together with Frans and a senior operator at a machining line, a sensor was identified that would be helpful to continuously collect from. The senior operator at a machining line explains the problem:

> *High-pressure mixture of water and detergent flows through the lance and out through small holes in the lance. The mixture then flushes the oil channels inside the cylinder head before handing them over to the assembly line. The pressure is important because it ensures burrs disappear from machined edges. Many of the burrs cannot be visually confirmed to have been removed, therefore it's important that the pressure is stable otherwise you will have problems later in the process*

This shows that the pressure is important, gaining a deeper understanding and being able to make decisions based on data, for example, condition-based maintenance could in the long run reduce the risk of unexpected stoppages.

Today the pressure is built up in pumps that have an outflow through lances. The holes of the lances wear and get bigger over time, they can also loosen chips, which causes the pressure to decrease. Then the operator must manually increase the power of the pumps to achieve the desired pressure again.

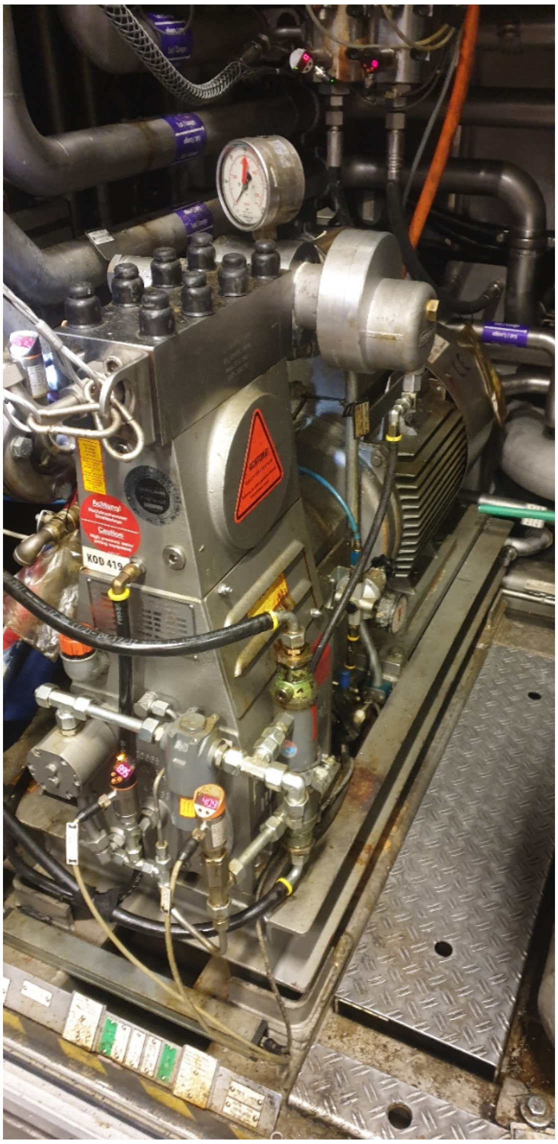

Figure C.2: Overall view of the pumps that pressurize detergent to the lance

To keep track of the pressure, pressure sensors are placed in between the pump and the lance. This sensor has an output signal of 4-20 mA and a measuring range between 0 to 600 bar [3]. The sensor is connected to the PLC and can be monitored through the HMI.

Figure C.3: pressure sensor

Regarding how the problem is handled today the senior operator says that:

> *Today we get a warning if the pressure in a cycle is too low or too high, but if the cycle after is "correct", the warning disappears. If the operator detects a pressure alarm, they check when the machine runs a couple of cycles, watch, and reflect on what to do. The pressure is not stored today so we can not look at historical data.*

Discussions were also held regarding wants and needs on technical solutions, which are presented below:

Requirements from evaluation case with machining department

- Requirement: Must not take time or disturb the machining production
- Easily be able to see a graph with the pressure over several cycles
- Requirement: Should be able to handle the output current of 4 to 20mA from the pressure sensor and transfer it through the technical solution

The first requirement mentioned is a previously mentioned requirement from several other stakeholders, reinforcing that the requirement is important. The second and the third requirement is outside of the scope of the project, the focus of projects is data collecting and transferring data to a database, not from the database back to for example operators.

C.8 Assembly Evaluation Case

Lars addressed an evaluation case regarding collecting alarm history from machines. Today, alarm logs must be collected manually with USB from the machines PLC and then synced and compiled with other production data, this is done manually and is time-consuming. Collecting the alarm history is also a problem for the machining department. Today, data is collected via Clamator, which logs machine status, but the alarm code (cause of the alarm) is not sent and needs to be gathered manually via USB from each unique machine's PLC. The work requires several different programs to compile and sync the data. The problem is addressed by both Assembly and Machining, expressing that it is a problem to manually retrieve the data.

Requirements from evaluation case with assembly department

- Automatically in real-time be able to collect alarm logs from PLC.

C.9 Energy Simulation Evaluation Case

Rasmus recommends contacting Julius, Energy optimizer, to get a more concrete understanding of how to measure and log energy data. This was done by carrying out a Gemba method presented in section 3.1.5 figure 2.1 (*Define the purpose of the Gemba visit*):

- Step 1: The reason we made the visit was to gain a better understanding of how and where energy data is collected today.
- Step 2: During the meeting with Rasmus, a meeting was booked with Julius. Questions were prepared so that they go in line with what was the goal to get out of the visit.
- Step 3 & 4: We met Julius and discussed the questions and concerns we had.
- Step 5 & 6:These two steps are described below.

According to Julius, not much energy data is collected today, it happens in some unique machines or on a larger level where, for example, entire lines are piled up on a current meter. It is not possible to see the power consumption of individual machines during different stages of production (e.g. when the machines are idle or are running)

When data is requested, one needs to go to the machine and manually make measurements of what was requested. This is a very time-consuming process that Julius does not have the resources to take care of.

In order to be able to continuously provide real-time energy data, it is required that the current is measured automatically, at the moment Aurobay does not have sensors in place to do this. After consulting with Julius he suggests that the evaluation case should focus on measuring 100A since it is a typical size at Aurobay. A sensor was found that could handle from 5 to 150A with an output signal from 4 to 20 mA [2].

Requirements from evaluation case with the stakeholders' Simulations of energy consumption

- Should be able to handle the output current of 4 to 20 mA from the current sensor measuring 100 A

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