



Jani Tarkiainen

Calculating and visualizing the OEE of a production line fastening robot

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Abstract

Author: Jani Tarkiainen
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The objective of this thesis is to propose a tool to monitor a fastening robot located at an assembly line. The company this thesis is performed for wants to monitor the activity of the robot to optimize the use of the robot and the assembly line. The aim is to perform overall equipment effectiveness calculations of the fastening robot and then visualize the findings in a Microsoft Power BI report.

This thesis is based on interviews with the company's Advanced Analytics Specialist and System Development Specialist alongside knowledge acquired by doing research on relevant topics concerning the objective. The course of this project follows a research approach and a schedule created in the beginning of the project. According to the project schedule the thesis first investigates the current state analysis, which includes an overview of the production assembly line and the data flow of the assembly. Following the current state analysis is the conceptual framework where theory is researched on five different topics. Together these two stages are the base where the proposed outcome of the project is built on.

The outcome of the thesis is composed of four parts: analysis of the current state, overall equipment effectiveness calculation, visualization of the data in form of a Power BI report and a final presentation. The report provided is created keeping the desired features in mind to match the need of the company and the proposal is validated with the company before providing the final version. In addition, in the final chapter of the thesis, suggestions for further development are proposed. This thesis supports the company in development of their production performance and leading their decision making with the use of data.

Keywords: Overall Equipment Effectiveness, Microsoft Power BI, fastening robot, visualizing

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Tämän insinööriyön tavoitteena on tarjota työkalu, jolla tutkia tuotannon asennuslinjalla sijaitsevaa ruuvausrobottisolua. Yritys, jolle insinööriyö suoritetaan, haluaa seurata robotin toimintaa optimoidakseen robotin ja tuotantolinjan käyttöä. Tavoitteena on suorittaa KNL-laskenta eli käytettävyyden, nopeuden ja laadun laskenta, jonka pohjalta luodaan Microsoft Power BI -raportti, jossa visualisoidaan laskennan tuloksia.

Insinööriyö perustuu haastatteluihin yrityksen ”Advanced Analytics Specialist” ja ” System Development Specialist” työntekijöiden kanssa sekä tutkimustyöhön, joka on tehty projektin tavoitteen mukaan oleellisista aiheista. Projektin kulku seuraa insinööriyön alussa tehtyä tutkimussuunnitelmaa sekä aikataulusuunnitelmaa. Aikataulun mukaan insinööriyö tutkii ensiksi nykytila-analyysiä, jossa annetaan yleiskuva tuotantolinjasta sekä kuvataan datan kulkua asennusvaiheessa. Nykytila-analyysin jälkeen insinööriyön seuraava vaihe on kirjallisuuskatsaus, jossa on tutkittu teoriaa viidestä eri aiheesta. Yhdessä nämä kaksi projektin vaihetta luovat perustan, jonka pohjalta yritykselle tarjottu lopputulos on rakennettu.

Insinööriyön lopputulos rakentuu neljästä osasta: nykytila-analyysistä, KNL-laskennasta, datan visualisoinnista Power BI -raportin muodossa ja loppuesityksestä. Yritykselle tarjottu raportti on luotu pitäen mielessä alussa sovitut halutut ominaisuudet, ja lopputulos validoitiin ennen lopullisen version palauttamista. Lisäksi insinööriyön viimeisessä kappaleessa annetaan jatkokehitysehdotuksia. Tämä insinööriyö tukee yrityksen tuotannon suorituskyvyn kehitystä sekä datan käyttöä päätöksentekovaiheessa.

Avainsanat: KNL-laskenta, OEE-laskenta, Microsoft Power BI, ruuvausrobottisolu, visualisointi

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Appendix 2: Notes of CSA interview – Advanced Analytics Specialist

List of Abbreviations

OEE: Overall Equipment Efficiency

IGBT: Insulated Gate Bipolar Transistor

SQL: Structured Query Language

PLC: Programmable Logic Controller

DAX: Data Analysis Expressions

1 Introduction

This thesis project is done for Metropolia University of Applied Sciences and for one of the world's leading technology companies, ABB. The purpose of this thesis project is to offer ABB a needed tool to monitor a fastening robot in an assembly line. At this moment ABB does not have nor use anything to fulfill this need.

1.1 Business context & challenge

ABB is a globally recognized technology company, and it is one of the leading companies on their field of business. ABB focuses on four different business areas: Electrification, Motion, Process Automation and Robotics & Discrete Automation. ABB operates in over one hundred countries and employs over 105 000 employees. (1.)

In Finland, ABB has facilities in twenty different locations, and in total ABB employs over 5 000 employees. It is one of the largest employers in the country. There are four major facilities which have factories integrated in them. Two of those are in Helsinki: Pitäjänmäki and Vuosaari. The other two are located in Vaasa and Porvoo. (2.)

This thesis concentrates on the Motion business area and its division, Drive Products and their facilities in Pitäjänmäki, Helsinki. ABB in Pitäjänmäki manufacture and develop motors and frequency converters which are commonly called "drives". The drives that ABB manufactures are low voltage frequency converters. For their drives ABB offers different software tools for all applications and industrial fields around the world. (3.)

For one of the frequency converter production lines in Pitäjänmäki factory ABB acquired a fastening robot in year 2020. The purpose of this robot on this production line is to:

- increase the efficiency
- reduce the number of errors
- obtain data of all the steps it does
- gain knowledge on how to operate fastening robots

The robot has two jobs. One is to fasten six IGBT modules to the drives coming through the production line. The second is to connect the drives frame and middle frame to each other. IGBT modules are small control cards that control the activity of the drive. These are crucial parts of the drive and even a small error can cause problems in the usage of the drive in the future. To avoid these problems ABB acquired a robot to perform this part of the production.

The robot collects data of its use and all the actions it takes. This data is available, but ABB do not utilize the data as much as they could at the moment.

1.2 Objective & outcome

The objective of this thesis project is to understand better the robot's activity using the data it collects. Understanding the data better enables making meaningful decisions around the production line where the robot operates. In addition, when creating a functional operating model about analysing data of this production line and robot, it is much easier to introduce a similar robot to somewhere else in the factory. Following a ready-made model rather than starting from scratch will save time on making the new robot as effective as possible.

Outcomes of the thesis are presented in table 1 below.

Table 1 Outcomes of the thesis

Outcome	Description
Analysis of the current state	Analysing how the steps of the current process happen from start to finish. Explaining where the data comes from and how it ends up where it can be manipulated.
Overall equipment effectiveness calculation	Completing the necessary calculations to receive the overall equipment effectiveness values.
Visualization of data	Presenting the data visually to help understand the data and to make decisions based on the data easier. Visualization is carried out on the Microsoft Power BI platform. A report is created where different findings from the data are presented.
Final presentation	Final presentation is to present all findings and outcome of the thesis.

1.3 Scope & outline of thesis

The Scope of the thesis project includes the outcomes listed on table 1 “Outcomes of the thesis” and the thesis itself.

This thesis consists of seven main chapters:

1. Introduction
 - Introduction to the thesis and what it is about.
2. Methods and material
 - Describing how the thesis project is carried out. What is done in different sections of the thesis. Additionally, the materials used for the thesis are presented.
3. Current state analysis
 - Describing and analyzing the areas that are under focus in this thesis, before any actions are performed.

4. Conceptual framework

- The conceptual framework is the theory and research done in this section. The theory is used in the next section together with the current state analysis findings to build the initial proposal for the case company.

5. Initial proposal

- This is what is provided to ABB by this project. After this chapter the outcomes can be modified and improved if in the validation process something is discovered.

6. Validation

- Initial proposal is presented to ABB in order to get valuable insight, feedback and improvement ideas.

7. Conclusion

- Going through the main points of the thesis project. Summarizing and evaluating the entirety of the project.

In the next chapter the material used in this thesis are presented in table format. The schedule of the project is shown and described alongside the methods used to complete it.

2 Methods and material

This section includes an overview of the methods and material used in this project. It contains research approach, data collection, and project schedule.

2.1 Research approach

During this project data is collected from two different sources:

- ABB employees
- fastening robot used in production

This data is crucial when building the current state analysis in chapter 3 and the initial proposal in chapter 5. The data is received from interviews with the ABB employees from various positions.

Interviewing people is a qualitative method of research. Qualitative methods are used to get detailed information from a small sample of subjects. Important in qualitative research is to acquire a depth of understanding using people's subjective experiences. (4, p. 9.)

Qualitative research methods, such as interviewing, serves the needs of this project. When creating the initial proposal, the data gathered from the interviews are used to support the proposal. Finding and selecting the right data and the desired data from the fastening robot is easier with the input from people experienced in similar matters.

The other main source of data in this project is the fastening robot. The robot transfers the collected data to a SQL database. The data type is different from the interview data. It comes in vastly larger quantities, and it has much simpler

values. An open interview question can generate a complex description of something, whereas one data value from the robot could be just a number.

Acquiring this type of data is done with quantitative research methods. Quantitative data is statistical data, often from a large sample. Quantitative research is a tool to reveal patterns, correlations and causal relationships by testing relationships between variables. (4, p. 9.)

The data that the robot collects is not presented nor explained in detail due to it being business sensitive data.

2.2 Data collection

The data for this project is gathered from ABB employees and from the fastening robot. The collected data is utilized in completing the current state analysis and in building the proposal. The collected data has been visualized in the following table 2.

Table 2 Data collected for the project

	Participant/source	Data type	Topic/description	Time	Documentation
	Data 1 - Objective				
1	Advanced analytics specialist	Meeting	Objective of the project	5.9.2022 35min	Meeting notes
	Data 2 - Current state analysis				
2	System Development Specialist	Interview	Data flow of the fastening robot	30.9.2022 30min	Meeting notes & recording
3	Advanced Analytics Specialist	Interview	Overview of the production line	4.10.2022 25min	Meeting notes & recording
	Data 3 - Data from the fastening robot				
4	Fastening robot	Statistical data	Data from the production line	?	SQL

2.3 Project schedule

To ensure timely completion of this project, a schedule was created. Figure 1 presents the schedule and timeline of this project using a Gantt chart.

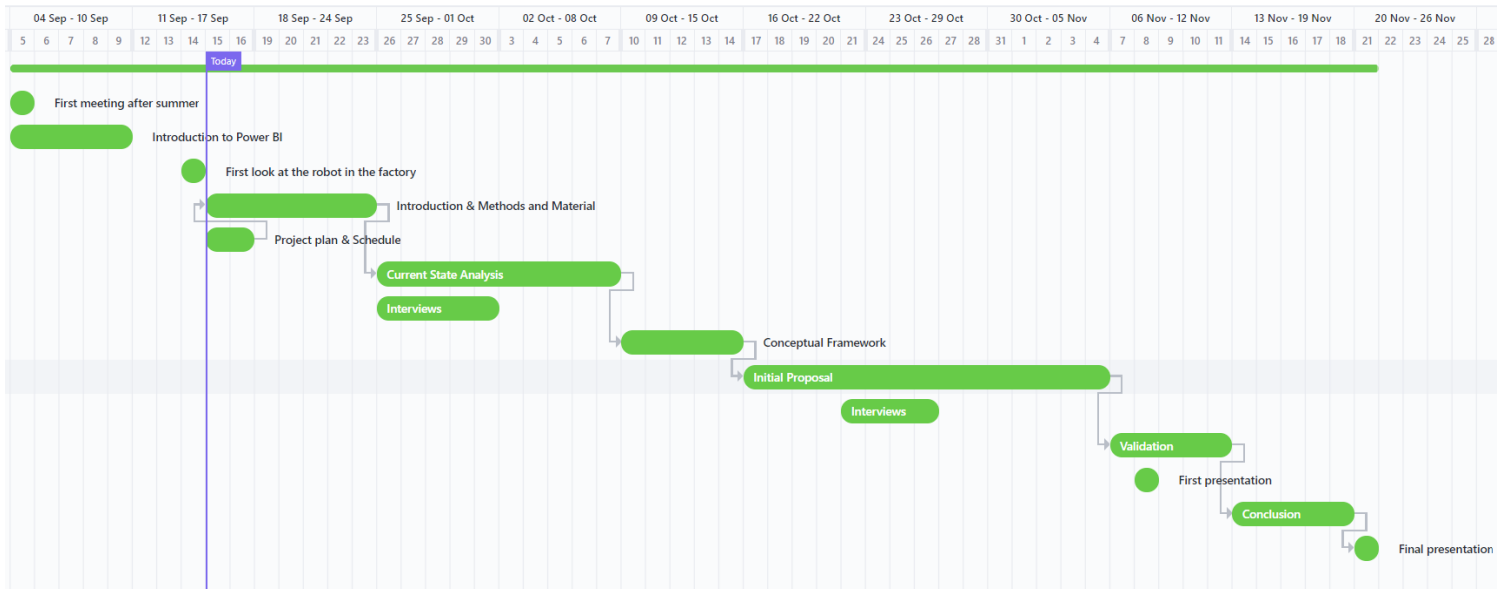


Figure 1 Project schedule presented with a Gantt chart

In May and in the beginning of June there were three preliminary meetings held concerning this thesis project. Those meetings are not included in the figure 1, Gantt chart, since the project officially started in September. Those three meetings were held to make sure that the project can begin without any complications in September.

The first meeting in September was held on the 5.9.2022. In this meeting the next steps of this project were agreed on. After the meeting some introduction practice on the Microsoft Power BI platform was completed. And then on the 14.9.2022 the first look of the robot cell in the factory took place.

After these steps the thesis project begins with writing of the chapters "Introduction" and "Methods & material". When the first two chapters are completed the current state analysis is conducted with interviews of ABB

employees. Conceptual framework consist of the theory used to validate the outcome of this thesis project. Initial proposal is the end product of the project. The last two chapters validation and conclusion finalise the thesis, and the project is finished on the 21.11.2022 with the final presentation.

The next chapter “Current state analysis” will give an overview of the production line where the fastening robot is located and describe how the data from the fastening robot is collected based on the employee interviews. Where the data is manipulated, and the data format is explained.

3 Current state analysis of the fastening robot and its data

In this third chapter more detail is given on:

- the production line
- data flow process
- data content.

This is done to gain better understanding about the operation of the production line where the fastening robot is located.

3.1 Introduction and methods of the current state analysis

The current state analysis stage was begun by making a plan. The topics of the current state analysis are introduced to give more context about the main sections related to this project.

The information for the current state analysis was received by conducting two interviews with ABB employees. The interviews are visible in table 2 “Data 2 – Current state analysis”. Data source 2, an interview with a System Development Specialist, gave insight and material about the data flow between the fastening robot and the software that ABB use. Data source 3 is an interview with an ABB Advanced Analytics Specialist. The interview topic was overview of the production line.

The objective of the project is to understand the behaviour of the robot based on the data it collects and to use the data, to make better decisions concerning the robot usage. The interviews and the current state analysis is the foundation to the outcome of the project. Trying to find the right data and how to present

the data would be infeasible without understanding the operation of the production line and what data the robot collects.

3.2 Overview of the production line

In the ABB factory in Pitäjänmäki, Helsinki the fastening robot is located between two production lines. Both of the production lines manufacture similar drives but in different sizes. Below figure 2 showcases the layout and the process flow of the two production lines and the fastening robot.

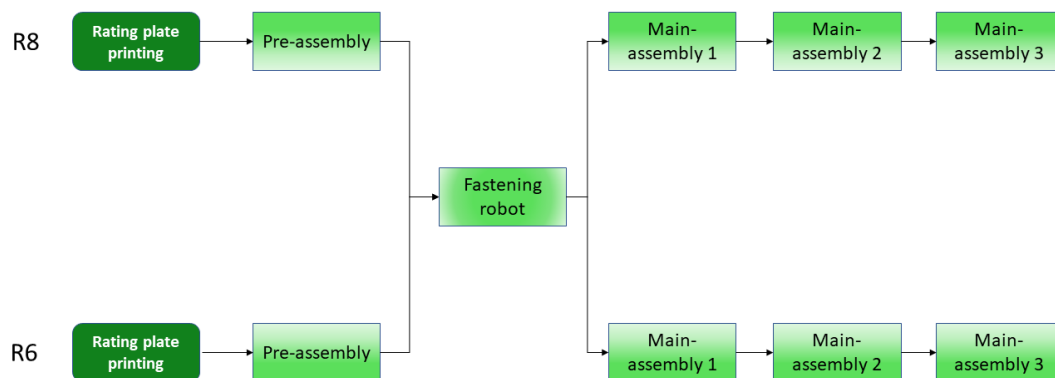


Figure 2 Layout and process flow of the production lines

R8 and R6 in figure 2 represent the size of the drive. Drives in Drive Products are labelled by their frame size. Frame sizes vary from R1 to R11. R1 being the smallest and R11 being the largest. R6 frames and R8 frames have their own production lines, and the fastening robot is planned to operate on both of them. At the moment only the R8 production line uses the fastening robot. It is planned that on spring 2023 the R6 production line would start using the fastening robot as well. (5.)

There are four different types of drives manufactured on both of these production lines:

- ACS880-11
- ACS880-31
- ACH580-31
- ACQ580-31

ACS880, ACH580 and ACQ580 represent different product families. ACS880 drives are industrial drives and ACH580 and ACQ580 drives are general purpose drives. “-11” means that the drive is a regenerative drive module and “-31” drives are ultra-low harmonic drives. The power of these drives vary from 15kW to 110kW. (5.)

These drives are mass produced on the two production lines. The fastening robot takes around 4% of the lead time of one drive. The drives are finished manually after the fastening robot has done its part. These two production lines cover approximately 6% of the Drive Products, Helsinki daily volume of frequency converters. (5.)

3.3 Data flow of the assembly

The fastening robot transfers data with two external entities. One of them is ABB's own SAP system. SAP is an enterprise resource planning program that ABB uses to run their production and business. The other one is a physical computer that is next to the fastening robot in the production line.

The process begins when a rating plate is printed on to the drive. Rating plate contains the drives serial number and its technical information, all the data is stored under this number. The serial number is created in SAP and sent to the computer alongside the IGBT location data. The serial number identifies the steps needed from the robot, including the IGBT location data. The fastening robot

scans the serial number and if all the data match with the data it received from SAP, the assembly begins. A start message is sent to SAP. The fastening robot gets data of the assembly using a PLC computer. When the assembly is completed the fastening robot sends the collected data to SAP and to the computer where the data is stored in an SQL database. Also, a stop message is sent to SAP. In figure 3 the data flow process is presented visually. (6.)

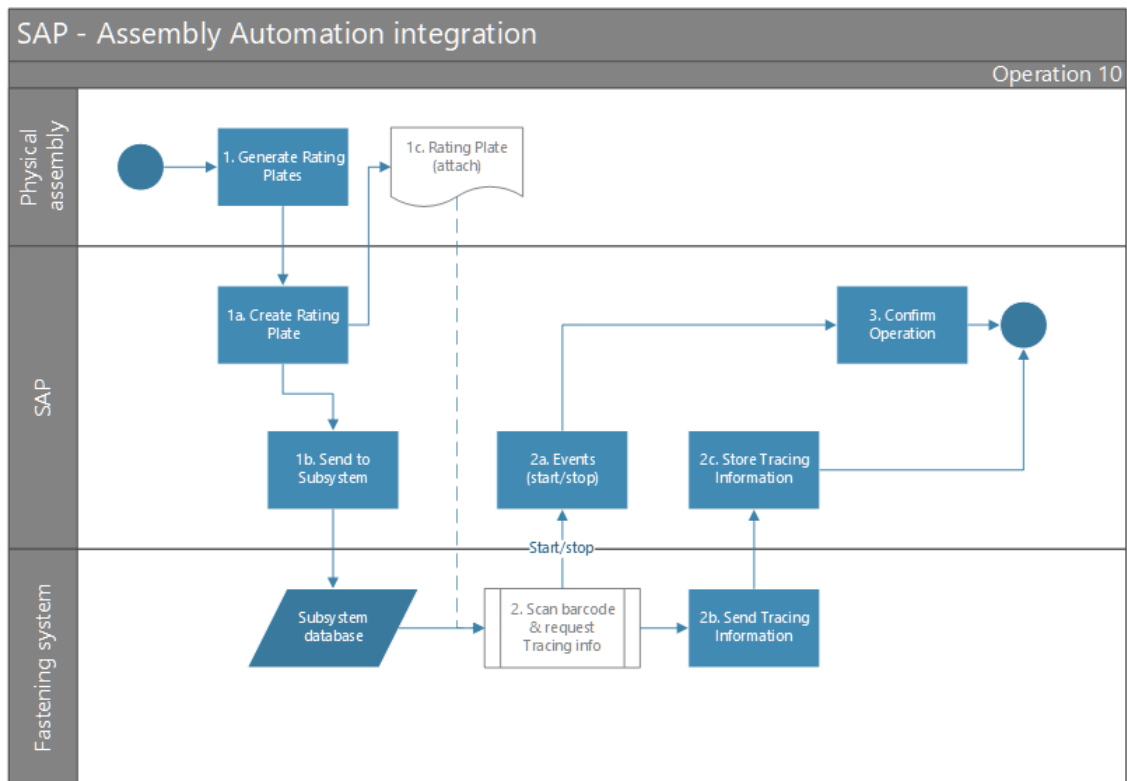


Figure 3 Data flow process chart of the assembly (6.)

In figure 4 the process event messages of each step of the assembly are presented in SAP.

IoT Message Monitor

Change selection Refresh IoT Systems Show tree

Messages									
Stat...	Dire...	IoT System ID	IoT Message Event	Msg....	Msg.Sta...	Object	Plant	Created on	Created...
🟢	←	ABB_ROBOT_CELL2019	RatingPlateInfoSend	OUT	OK	106711655	0001	21.09.2022	██████████
🟢	→	ABB_ROBOT_CELL2019	OperationStart	IN	OK	12238	0001	21.09.2022	██████████
🟢	→	ABB_ROBOT_CELL2019	TracingDataImport	IN	OK	12238	0001	21.09.2022	██████████
🟢	→	ABB_ROBOT_CELL2019	OperationEnd	IN	OK	12238	0001	21.09.2022	██████████

Figure 4 Process event messages in SAP (6.)

The event messages contain the time stamp of the event, info message about the event and the serial number of the drive that was assembled.

The data that the fastening robot collects of the assembly steps are stored in the computer next to the robot on the line. This data gives more detailed picture of the robot's activity. The data is stored in a SQL database. The data need to be manually collected from the computer at the time of this project, but it is planned that the data would transfer to a cloud storage in the future. (6.)

In the next chapter, Conceptual framework, multiple topics of theory relating to the objective of this project are depicted. These topics were researched in order to broaden the knowledge of them to aid in the completion of this project.

4 Conceptual framework

This chapter looks into the best practices and theory based on literature. The topics were chosen based on the meetings and interviews done prior to this part of the project. This chapter forms the framework for this thesis project and eases with the transition on to the next part of the project, Initial proposal.

In this chapter, five topics are looked into:

- Relational model
- SQL
- Star schema
- Overall equipment effectiveness
- Microsoft Power BI

4.1 Relational model

In 1970 Edgar Frank Codd created the relational model where data is represented in a set of separate tables, this is what the relational databases are based on. These tables would have relationships between each other that link them together. Relational databases are usually managed with the programming language SQL. Figure 5 is an example of a relational model. (7, p. 4-5.)

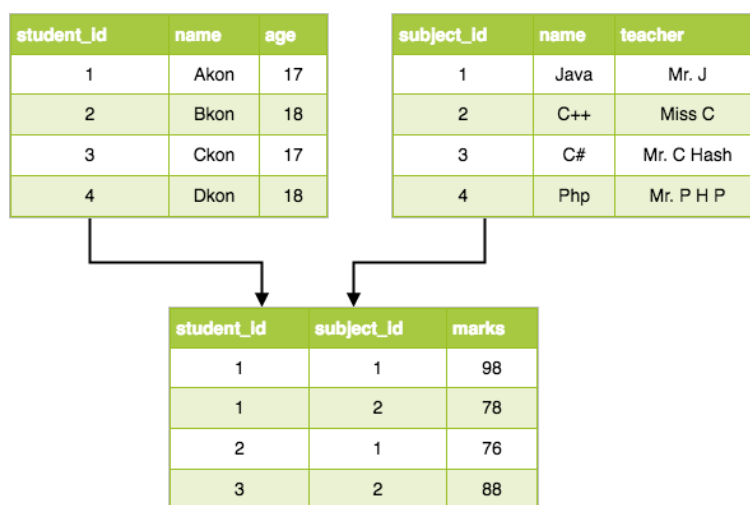


Figure 5 Example of a relational model (8.)

In the example of a relational model in figure 5 relationships between the tables are expressed with arrows. The top two tables have a primary key that identifies each row of the table. In figure 5, column “student_id” identifies each student with a numeric value. Student 1 is Akon, age 17. The primary key in the table on the right is “subject_id”. For example, subject 2 is C++ which teacher is Miss C. On the last table there is not any primary keys but there are two columns where a single value can identify a row in the other two tables. Those are called foreign keys. For example, third row in the last table: student 2, Bkon age 18 got 76 as their mark in the Java course from Mr. J. (7, p. 5-7.)

4.2 SQL

SQL, abbreviation from Structured Query Language, is a programming language that is used to generate, manipulate and retrieve data from relational databases (7, p. ix). Relational databases can be used with a relational database management system (RDBMS). RDBMS is a program that is used to administer, create and update relational databases. Relational database management systems commonly use SQL in order to access the databases. (9.)

SQL is a declarative programming language. Declarative languages depend more on the features of the language used. Whereas the other popular programming method, imperative programming, depends more on specific instructions by the user. In declarative programming user describes what it wants to achieve, and the language puts out the result in the best way possible. Imperative programming requires more explicit step-by-step instructions. Table 3 compares the differences of declarative and imperative programming methods. (10.)

Table 3 Declarative programming vs imperative programming (10.)

Declarative programming	Imperative programming
User sets conditions, program executes	Step-by-step instructions
Less complex and less code	Longer and more complex code
Customizing can be more challenging	Complete control when customizing

4.2.1 History of SQL

SQL was created in the early 1970's by Donald D. Chamberlin and Raymond F. Boyce who were working for IBM at the time. Chamberlin and Raymond created SQL, then called SEQUEL, on the base of Codd's relational model. They first presented SEQUEL in 1974 in their paper "SEQUEL: a Structured English Query Language", where they explained the language and showed examples of it. (11, p. 249-259.)

In the 1970's when Chamberlin and Boyce were working at IBM, one of the biggest trends in computer science was developing systems and languages for handling persistent data. Persistent data is data that is meant to remain inside a computer system until it is explicitly deleted by an external user. Chamberlin and Boyce motive when creating SQL was a programming language that would be widely accessible. Even for users who are unable to access formal training in mathematics or computer programming. The first step was to replace symbols with keywords. Figure 6 compares symbols in relational algebra to keywords in SQL. Chamberlin and Boyce also wanted to allow the language to be able to make database updates and administrative tasks for example, creating new tables. This was not usually a feature in query languages at the time. (12, p. 78-79.)

\bowtie	Join
π	Project
σ	Select
ρ	Rename

Figure 6 SQL keywords (12, p.79)

4.2.2 SQL command types

SQL commands can be divided into five groups. Those groups are DDL, DML and DCL. Each of the command types are meant for different purposes. Examples of commands for each type are given in figure 7.

- **Data Definition Language (DDL)** is used when defining a database. Main functions are creating tables
- **Data Manipulation Language (DML)** commands are for maintaining databases. DML commands are for inserting, deleting and updating tables
- **Data Control Language (DCL)** is for controlling databases. With DCL commands administrative controls can be set or if certain user is allowed to perform certain operations. (13, p. 113-114.)

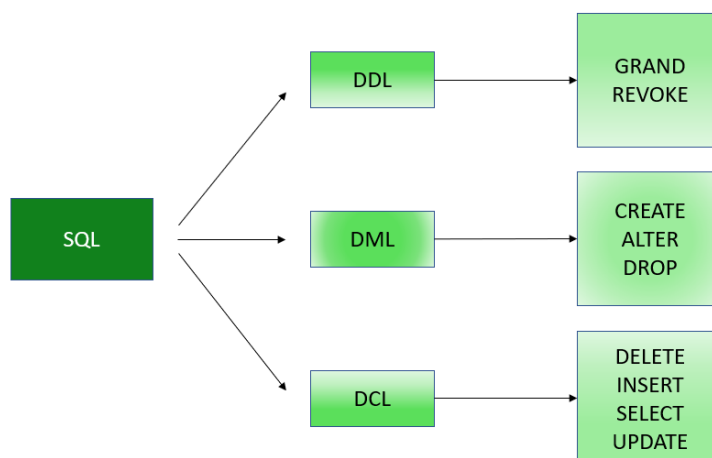


Figure 7 Examples of SQL command types (13, p. 114.)

4.3 Star schema

Data mart is a smaller definite part of a data warehouse that is important for a selected part of an organisation. Data marts are usually focused on particular subject area. (14.) Data mart is a tool that is usually used to create a multi-dimensional analysis, an analysis with multiple different dimensions such as product, time and location. (15, p. 7.) Star schema is a style of a data mart, and it is used to de-normalize complex data models (16, p. 198; 17.)

Star schemas consist of one fact table in the middle and surrounded by a number of dimensional tables. The fact table generally contains numeric and quantitative values, measures of the subject area. Dimensional tables generally consist of textual and qualitative descriptions to provide context for the facts. The fact table connects to the dimensional tables with foreign keys inside the fact table. The dimensions are for filtering and grouping data. The name “star schema” is given since the data model resembles a shape of a star, as seen in figure 8. (15, p. 8-9.)

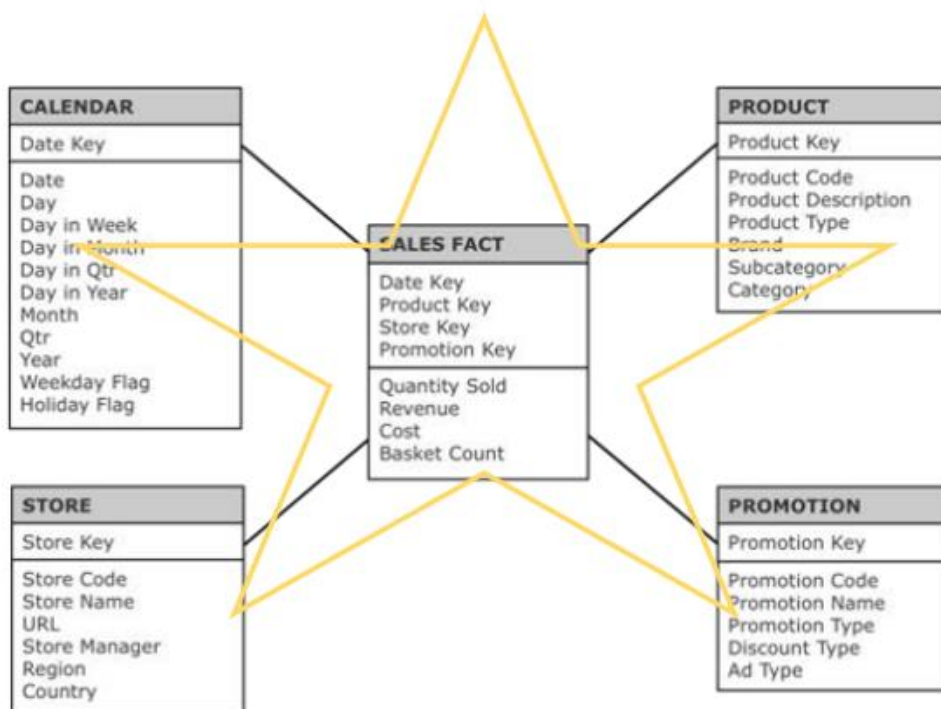


Figure 8 Example of a star schema (15, p. 8.)

The most notable advantage of the star schema is its simplicity. When there is less tables and joins it is much simpler to create the desired queries and to find the right data. In addition, usage of the data for people that are not orientated on that data model in question is much easier compared to a highly normalized data model. (15, p. 9-11.)

4.4 Overall equipment effectiveness

Overall equipment effectiveness or OEE is a measurement of total equipment performance. With OEE it is measured that are the equipment performing at a level that they are supposed to perform. Identifying the parts of the process that need improvement can be done using OEE since it points out the parts that are lacking in performance. OEE is an analysis of three different parts of the process:

- availability
- performance
- quality (18, p. 3518-3519.)

Overall equipment effectiveness =

Availability × performance efficiency × rate of quality products

Equation 1 Formula of overall equipment effectiveness (19, p. 27.)

Seiichi Nakajima introduced the formula for OEE, visible on equation 1, in 1984 by the Japan institute for plant maintenance. It was later translated to English in 1988. The result of the OEE formula is a percentage of how effective the equipment is used. If overall equipment effectiveness would be 100% it would mean that the equipment produce only quality products with the best possible operation rate for the whole available operation time. This is of course unrealistic and according to Nakajima the ideal overall equipment effectiveness should be greater than 85%. (19, p. 21-28.)

4.4.1 Calculating overall equipment effectiveness

Next, the steps followed when calculating OEE are explained with visuals from the Introduction to TPM by Seiichi Nakajima. Figure 9 presents the factors that are taken into account when calculating OEE.

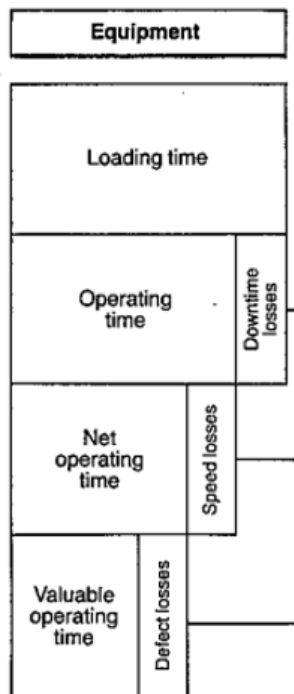


Figure 9 Factors taken into account when calculating OEE (19, p. 25.)

4.4.1.1 Availability

Calculating availability is the first step. The formula for availability is visualized in equation 2. Loading time is planned downtime subtracted from the total available time per day. Planned down time is for example scheduled maintenance or management activities. Operation time is then the time left when non-planned downtime is subtracted from loading time. Non-planned Downtime can be for

example failure stoppages or adjustment procedures. Availability represents the actual run time of the equipment. (19, p. 22.)

$$\begin{aligned} \text{Availability} &= \frac{\text{operation time}}{\text{loading time}} \\ &= \frac{\text{loading time} - \text{downtime}}{\text{loading time}} \end{aligned}$$

Equation 2 Availability formula (19, p. 22.)

4.4.1.2 Performance

When operating time has been received, the performance can be calculated. Performance is the result of the operating speed rate and the net operating rate, visible in equation 3.

$$\text{Performance efficiency} = \text{net operation rate} \times \text{operating speed rate}$$

Equation 3 Performance formula (19, p. 27.)

Operating speed rate refers to the ideal operating cycle time and the actual operating cycle time. Ideal operating cycle time is based on the equipment capacity as designed. Cycle time is the required time to complete a finished product from beginning to the end. Operating speed rate is visible in equation 4.

$$\text{Operating speed rate} = \frac{\text{theoretical cycle time}}{\text{actual cycle time}}$$

Equation 4 Operation speed rate formula (19, p. 24.)

Net operating rate measures how much of the operating time is actually used. It calculates the losses from minor stoppages and small problems that happen when using the equipment. Net operating rate is visible in equation 5.

$$\begin{aligned} \text{Net operating rate} &= \frac{\text{actual processing time}}{\text{operation time}} \\ &= \frac{\text{processed amount} \times \text{actual cycle time}}{\text{operation time}} \end{aligned}$$

Equation 5 Net operating rate formula (19, p. 26.)

In equation 6 the performance formula is explained. Where equation 3, 4 and 5 are combined to one. (19, p. 24-27.)

$$\begin{aligned} \text{Performance efficiency} &= \text{net operation rate} \times \text{operating speed rate} \\ &= \frac{\text{processed amount} \times \text{actual cycle time}}{\text{operation time}} \times \frac{\text{ideal cycle time}}{\text{actual cycle time}} \end{aligned}$$

Equation 6 Performance formula explained (19, p. 27.)

4.4.1.3 Quality

After net operating time, pictured in figure 9, is calculated the next step is to subtract quality losses from it. Formula for quality is presented in equation 7. The value for quality is the result when quality products (flawless products), defective products subtracted from total processed amount, are divided by the total processed amount. (19, p. 27.)

$$\text{Quality} = \frac{\text{flawless products}}{\text{actual output}}$$

Equation 7 Quality formula (20.)

4.4.2 6 big losses

The six big losses are defects in the process that reduce the equipment effectiveness. The losses are those factors that are taken into account when

calculating OEE. The six losses are categorized to three categories: availability, performance and quality. Each part of the overall equipment effectiveness calculation consist of two of the six losses. The six big losses are presented in figure 10 below. (18, p. 3519.)

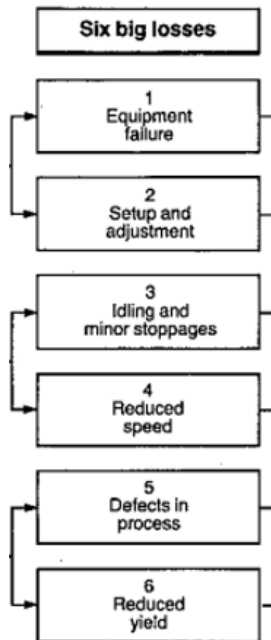


Figure 10 6 big losses (19, p. 25.)

Availability:

1. Equipment failure: this covers all the downtime caused by the failure of the equipment or a breakdown.
2. Setup and adjustment: setup and adjustment downtime means the lost time when changing from one item to another or when making small adjustments to the equipment.

Performance:

3. Idling and minor stoppages: these occur when temporary malfunctions happen to the equipment that are quickly fixed or when the equipment is idling, not doing anything.
4. Reduced speed: this refers to equipment design speed versus actual operating speed. If more time is spent on one item than it should, it is reduced speed loss.

Quality:

5. Defects in process: malfunctioning production equipment that cause losses in quality.
6. Reduced yield: contains all the defect items that are manufactured between start-up and stabilization. If preparation for shift change is poor, reduced yield is more likely. (18, p. 3519-3520.)

4.4.3 Summary of overall equipment effectiveness

Seiichi Nakajima created an example of the process of calculating OEE. It summarizes how the three parts are calculated with the six big losses resulting in a percentage figure representing overall equipment effectiveness calculated with theoretical values.

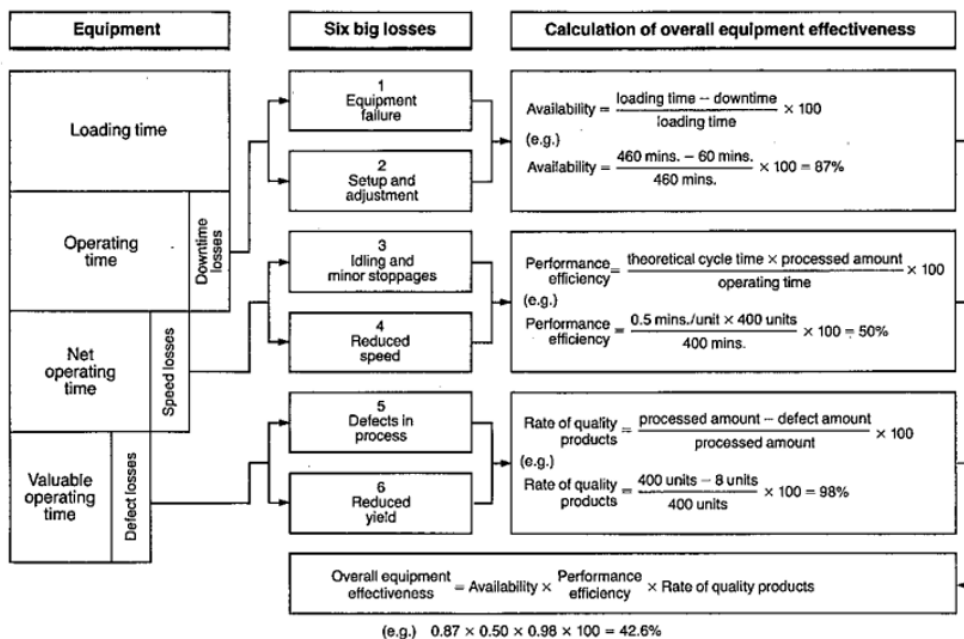


Figure 11 Summary of overall equipment effectiveness (19, p. 25.)

Figure 11 shows how values for availability, performance and quality are created and how the six big losses are related to the process. Overall equipment effectiveness in this theoretical example is 42,6%. Multiplying availability (87%), performance (50%) and quality (98%) result in the final OEE value (42,6%). (19, p. 22-29.)

4.5 Microsoft Power BI

Microsoft Power BI is a software that is used for data visualization, focused on business intelligence. Power BI was launched in 2015. (21.) Power BI combines multiple software, apps and connectors that work together to turn data into coherent and visually immersive form. Power BI's user interface was created to be quite simple to enable users to create reports and visualizations without much experience. With Power BI various data sources can be used. For example, Excel spreadsheets, SQL databases, cloud-based or on-premise data warehouses.

Power BI system consist of three main components:

- Power BI Desktop
- Power BI Service
- Power BI Mobile (22.)

Power BI desktop is mainly used to creating and sharing reports. Connecting to a data source, transforming and manipulating data to create a model, creating visuals and reports and then sharing them with Power BI Service are amongst the most common uses of Power BI desktop. Figure 12 shows an example of a Power BI desktop dashboard. (23.)

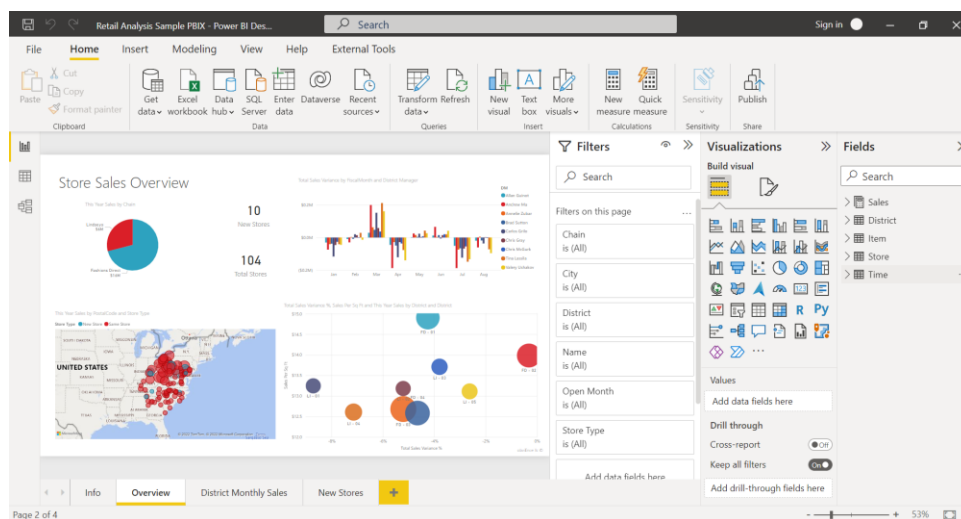


Figure 12 Power BI desktop dashboard (23.)

Power BI service is the cloud-based online version of Power BI. Services like Power BI service are called software as a service (SaaS). Power BI service and Power BI desktop have similar features but for example Service has limited options on modelling data. Service is used more on sharing reports and analysing the results. Differences between Power BI desktop and Power BI service are visualized in figure 13. (24.)

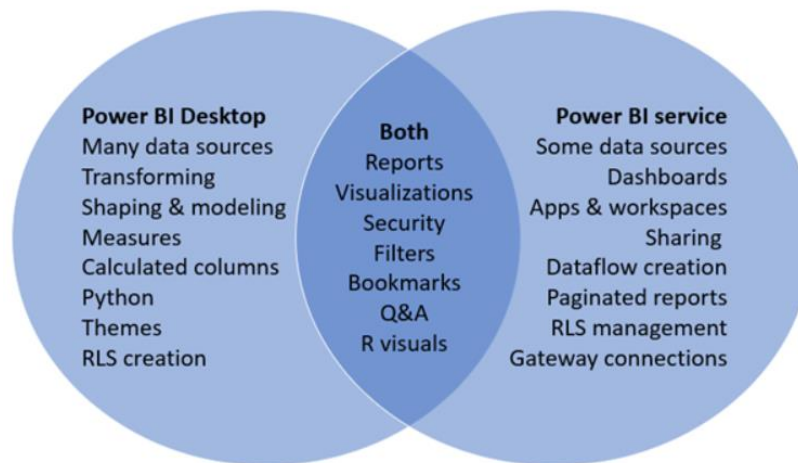


Figure 13 Venn diagram of differences between Power BI desktop and Power BI service (24.)

Power BI mobile is a mobile application of Microsoft Power BI. It is available for Android, iOS and Windows mobile devices. In the mobile version it is not possible to create reports and visualizations as it is in the desktop and service Power BI platforms. The reports are created in Power BI desktop and optimized for mobile usage using the mobile layout option. There are almost all the same formatting options available that are available for desktop and service versions. In figure 14 the mobile layout in the desktop version is presented. (25.)

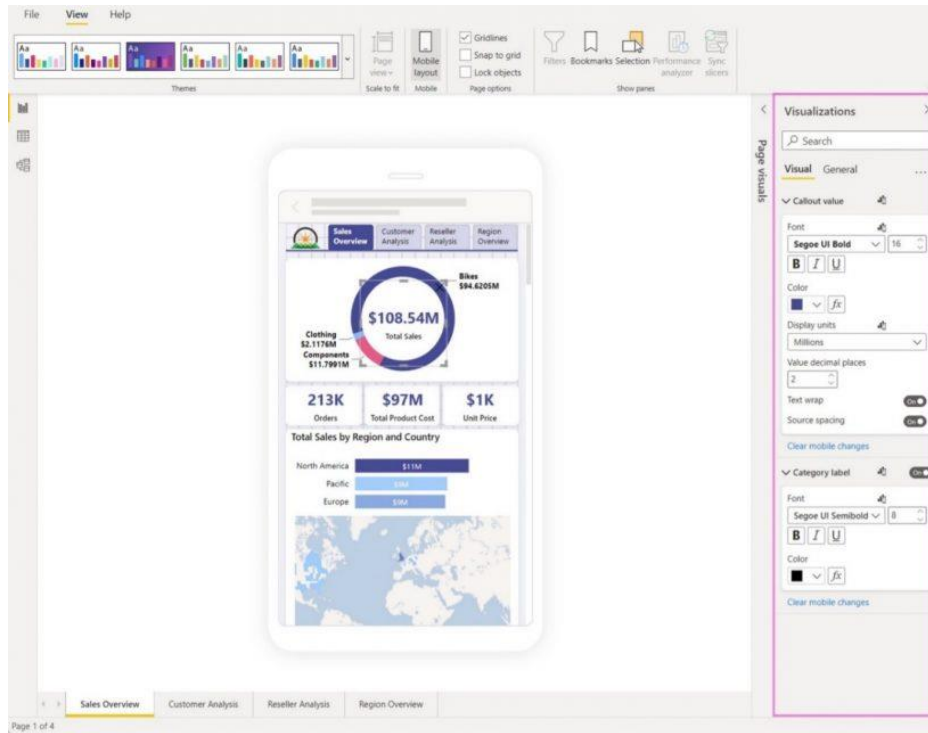


Figure 14 Power BI mobile layout in Power BI desktop (26.)

5 Initial proposal

This fifth chapter describes what is proposed as the solution for the issue given by ABB. An overview is provided of how this stage of the project was carried out with pictures and reasoning of the outcome at the end.

5.1 Overview of the proposal building stage

The objective of this project is to gain a better understanding of the robot and its activity, using the data it collects. Then, decision making can be based on the findings from the data.

The proposal is based on three different matters:

- objective and outcome agreed on with ABB at the start of the project
- findings of the current state analysis
- theory of the conceptual framework.

Beginning to build the proposal, the objective is kept in mind the whole time to align the work with the motives of this project. The current state analysis made understanding the objective easier. Knowing what happens in the process and how the data transfers between systems during the process is vital when deciding what is presented in the report. The theory of the conceptual framework laid the foundation for the work to be done for this initial proposal. Knowledge gained from the conceptual framework ensured the completion of the proposal. Especially the chapter "Overall equipment effectiveness" is important since the proposal contain the calculations explained in this chapter. Information learned about data modelling and the platform used to create the report were helpful when working on the proposal.

The proposal is built primarily with independent work and research using online materials about the subject. The platform used to create the proposal was Microsoft Power BI Desktop. There were not any additional interviews conducted during the building phase of the proposal. Weekly thirty-minute meetings with the ABB contact person were held. In those meetings possible problems and questions were discussed and solution ideas were received from the contact person. In addition to the weekly meetings, two meetings were held to tackle more urgent problems to prevent delaying the schedule.

Proposal building activity was recorded into a separate document where a diary of actions towards the proposal and the project were held. In Microsoft Power BI Desktop all the actions and steps done are also saved.

The report done for the initial proposal uses the data mentioned in chapter 3.3 “Data flow of the assembly”. This data is collected in the computer next to the robot on the assembly line. The data is accessed on Power BI through a SQL database. In this database there is data about amount of drives produced and the amount of non-planned downtime for example. The data in this database is from the start of March to the start of November of 2022.

5.2 Illustration and description of initial proposal

The outcomes of the project agreed on with ABB were the analysis of the current state, which is presented in chapter 3 “Current state analysis of the fastening robot and its data”. Overall equipment effectiveness calculation and visualization of the data were the next two outcomes and those are presented in the Microsoft Power BI report. Lastly, the final presentation is held at the end of the project at ABB premises with the contact person and other ABB employees involved on the project.

The two outcomes that are in the Power BI report are displayed in the following chapters. Chapter 5.2.1 describes how the OEE calculations are completed in the Power BI Desktop platform. Chapter 5.2.2 presents the report that is built to visualize the findings from the data and the calculations. The chosen visualizations and the reasoning behind them are explained.

5.2.1 Overall equipment effectiveness calculations

As explained in the conceptual framework chapter 4.4 “Overall equipment effectiveness” three values need to be calculated in order to calculate the OEE value. Those three are availability, performance and quality. First step of the proposal building phase is to calculate these values. It is done by following equations 2, 6 and 7.

Availability is calculated following equation 2 and by using DAX (Data Analysis Expressions), which is a formula expression language that is used in Power BI (27). In equation 8 it is presented how the value for availability is calculated in the report. Operating time per day represents the actual working time per day, this value is not shown in this chapter. From the picture the value representing the whole available working time per day in seconds is blocked.

```

1 Availability =
2 DIVIDE(
3     'DowntimeByDay'[Operating Time per Day],
4     [REDACTED])

```

Equation 8 Availability in DAX

Calculating performance using equation 6, net operating rate and operating speed rate need to be calculated first. Net operating rate, presented in equation 5, is constructed in DAX as seen on equation 9.

```

1 Net Operating Rate =
2 DIVIDE(
3     SUM('ThroughputTime'[ThroughputTime]),
4     SUM('DowntimeByDay'[Operating Time per Day]))

```

Equation 9 Net operating rate in DAX

For operating speed rate, equation 4 is used. On equation 10 it is written in DAX. From this equation the desired throughput time for a drive from this assembly line going through the fastening robot in seconds is blocked

```

1 Operating Speed Rate =
2 DIVIDE(
3     'UnitsProducedByDay'[Produced Drives Mittari] * 60,
4     SUM('ThroughputTime'[ThroughputTime]))

```

Equation 10 Operating speed rate in DAX

Performance can be then calculated with net operating rate and operating speed rate as shown in equation 11.

```

1 Performance =
2 'ThroughputTime'[Net Operating Rate] * 'ThroughputTime'[Operating Speed Rate]

```

Equation 11 Performance in DAX

Quality is calculated with equation 7. Since the frame R6 drives do not use the fastening robot at the moment for these calculations only the R8 drives are used. Quality calculations done in DAX are presented in equation 12.

```

1 Quality R8 =
2 DIVIDE(
3     ('UnitsProducedByDay'[R8 Total] - 'UnitsProducedByDay'[R8 Defective]),
4     'UnitsProducedByDay'[R8 Total])

```

Equation 12 Quality in DAX

With availability, performance and quality OEE can be calculated. It is written in DAX as presented in equation 13.

```

1 Overall Equipment Effectiveness =
2 'ThroughputTime'[Performance] * SUM(DowntimeByDay[Availability]) * SUM(UnitsProducedByDay[Quality R8])

```

Equation 13 Overall equipment effectiveness in DAX

5.2.2 Visualization of data

Visualization comes in the form of a Microsoft Power BI report. The initial proposal is the first version of the report. This version is evaluated by the ABB contact person in the validation stage of the project.

The first version of the report consists of eight different visualizations:

- line chart of availability
- line chart of performance
- line chart of quality
- line chart of overall equipment effectiveness
- stacked column chart of amount of produced drives
- card of amount of produced drives
- card of amount of defective drives
- table of downtime, and throughput time per drive

There is also a slicer on the report that allows the user to select a specific month or months to look at. If not selected the report portrays the whole year. In addition, if one week is selected from the stacked column chart, the other visualizations then show only the values from the selected week.

In the pictures presented of the report, the visualizations show values from the July of 2022. Numeric values are blocked from the pictures. In figure 15, on the line charts of availability, performance and quality, date is placed on the X-axis and percentage value is placed on the Y-axis. The line then displays the percentage value for each day of the month of July. The dashed line on the Y-

axis of each chart represents the minimum value for each three measurements to reach the desired overall equipment effectiveness value.

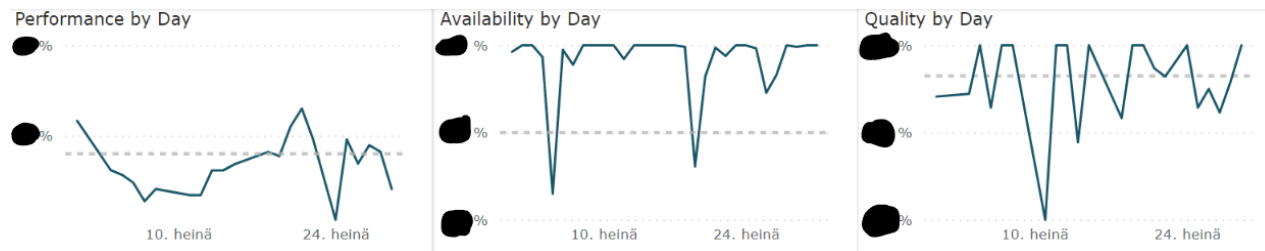


Figure 15 Line charts of availability, performance and quality

The OEE value is presented in a line chart as well, this is visible in figure 16. The difference in this line chart to the three previous ones are the target areas marked on the Y-axis. The green target area covers the values where ABB could set their target OEE values. The red target area on the other hand is for values that are labelled as not ideal. The data value markers highlight if the OEE value is inside of one of the target areas. Numeric values are blocked from figure 16.

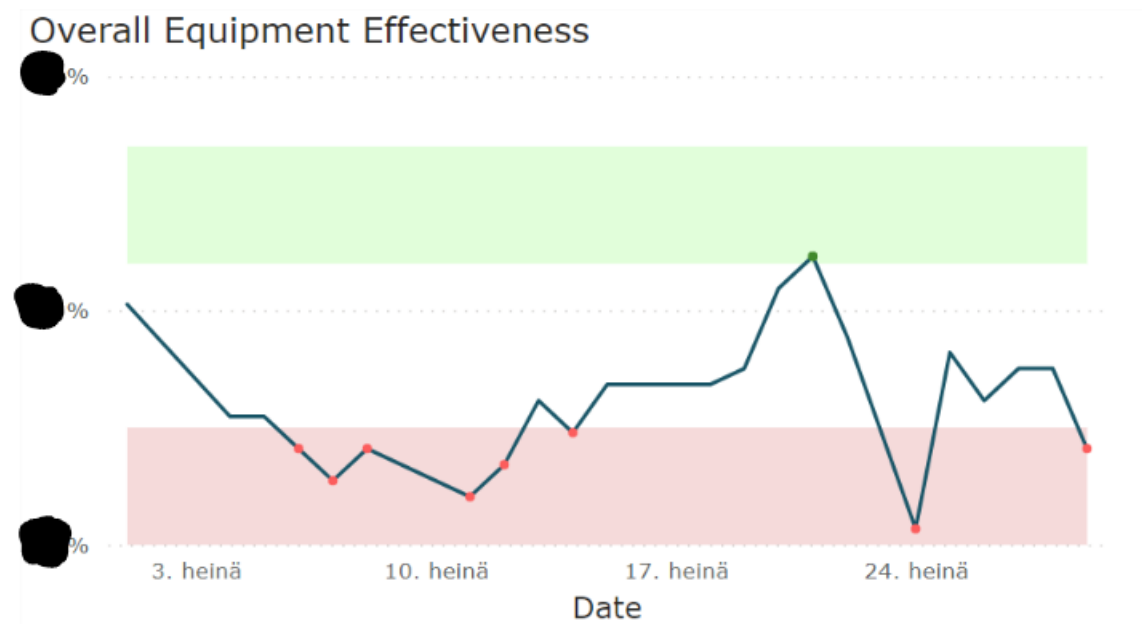


Figure 16 Line chart of overall equipment effectiveness

The amount of produced drives and defective drives are presented with a stacked column chart and cards showing only the numeric value. The cards are added to

highlight the values and to ease up the usage of the report for users. These are visible in figure 17. On the stacked column chart week number is placed on the X-axis and number of drives produced is placed on the Y-axis. The numeric values are blocked from figure 17.

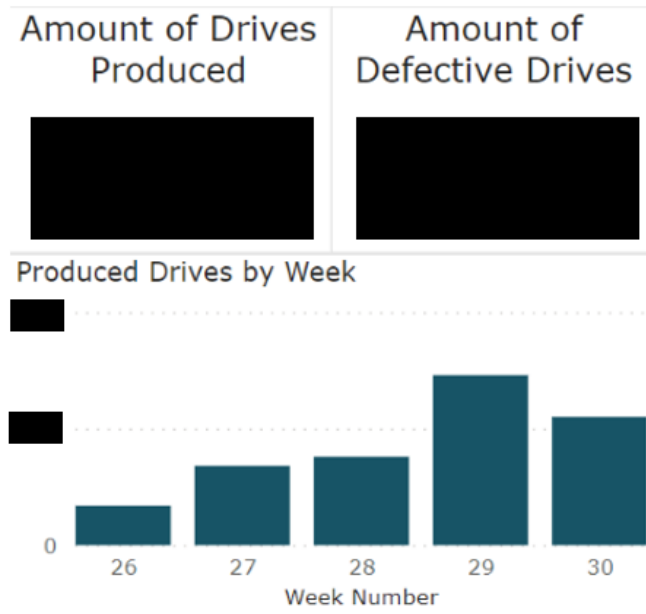


Figure 17 Amount of produced and defective drives cards and stacked column chart

The final visualization in this version of the report is the table of downtime, and throughput time per drive. Throughput time refers to the same meaning as cycle time in equation 6, where performance is calculated: the required time to complete a finished product from beginning to the end. In this context it is the throughput time of the fastening robot and not the whole assembly line. The table is visible in figure 18. The first column is the dates of the selected month, in this case July of 2022. The second column is the whole downtime for the dates of the selected month. The third column is the throughput time per drive for the dates of the selected month, which is calculated by dividing the whole throughput time of the day with the amount of drives produced. Numeric values are blocked from figure 18.

Downtime & Throughput time per Drive by Day (seconds)

Date	Downtime	Throughput Time per Drive
1.7.2022		
2.7.2022		
3.7.2022		
4.7.2022		
5.7.2022		
6.7.2022		
7.7.2022		
8.7.2022		
9.7.2022		
10.7.2022		
11.7.2022		
12.7.2022		
13.7.2022		
14.7.2022		
15.7.2022		
16.7.2022		
17.7.2022		
18.7.2022		
19.7.2022		
20.7.2022		
21.7.2022		
22.7.2022		
23.7.2022		
24.7.2022		
25.7.2022		
26.7.2022		
27.7.2022		
28.7.2022		
29.7.2022		
30.7.2022		
31.7.2022		

Figure 18 Table of downtime, and throughput time per drive

5.3 Summary

In the initial proposal the OEE calculations and visualizations were required by ABB to be achieved with this project. The other visualizations are created for the report on the base of the knowledge from the current state analysis and the conceptual framework. Purpose for the other visualizations is to bring added value for the user when analysing the OEE values of the fastening robot and to find reasons for the OEE values. Chosen visualization styles are selected to get the most informative way to present certain data. They are positioned on the

report, as seen in figure 19, in a way that the user has all of the information available on the same page.

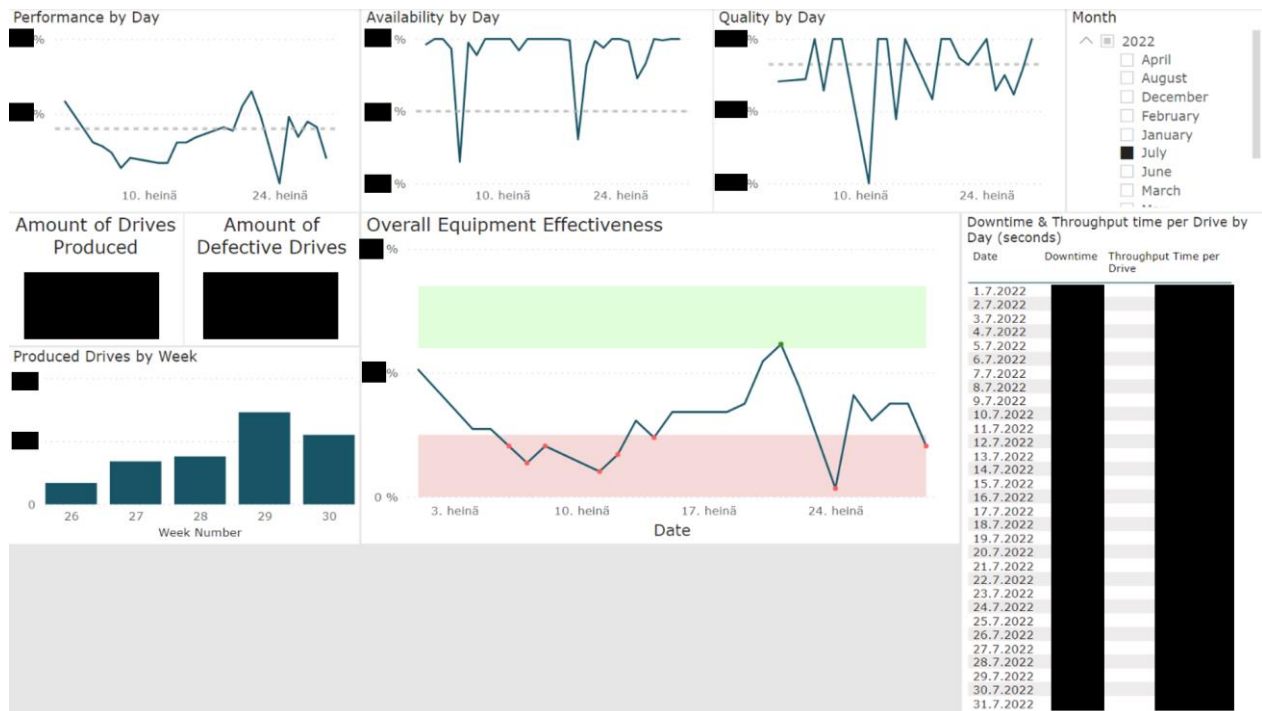


Figure 19 The first version of the report

Next chapter is the validation phase of the project. The initial proposal is reviewed by the contact person at ABB, and they will offer feedback and improvement ideas that are then implemented to the proposal.

6 Validation

The validation stage of this project was performed in order to receive feedback about the initial proposal and analyse the feedback and make the necessary updates to the proposal. After the possible changes are made, the final version of the proposal will be ready.

6.1 Overview of the validation stage

The validation was conducted with a meeting. The meeting was held together with the ABB contact person. In this meeting all parts of the initial proposal were presented to the contact person with detailed explanation. The meeting lasted for an hour and was held in Microsoft Teams.

The OEE calculations and the methods used to achieve the calculations presented in chapter 5.2.1 “Overall effectiveness calculations” were approved by the contact person. Below, on table 4, the feedback received about the visualizations presented in chapter 5.2.2 “Visualizations of data” are listed.

Table 4 Feedback received from validation

Feedback number	Visualization	Feedback	Applied
1.	Availability, performance & quality (figure 15)	Add a second Y-axis presenting the amount of produced drives to the charts	X
2.	Availability, performance, quality & OEE (figures 15 & 16)	Change the visuals to present the data on month level not day level	
3.	OEE (figure 16)	Change the green target area to a Y-axis constant line portraying the target value	X
4.	OEE (figure 16)	Remove the data point markers	X
5.	-	Add a topic heading to the report using an ABB template	X

6.2 Adjustments to the initial proposal

First adjustment to the proposal was feedback 1. Adding a secondary Y-axis to portray the amount of produced drives would improve the charts. Initially, the amount of drives produced were added to the three charts. Subsequently for the availability chart, produced drives on the Y-axis were changed to portray downtime and for the quality chart, produced drives were changed to the amount of defective drives. These changes were done to give the user of the report immediate reference to movements of the three lines. For the performance chart, the amount of produced drives stayed on the secondary Y-axis. The updated charts are visible in figure 20.

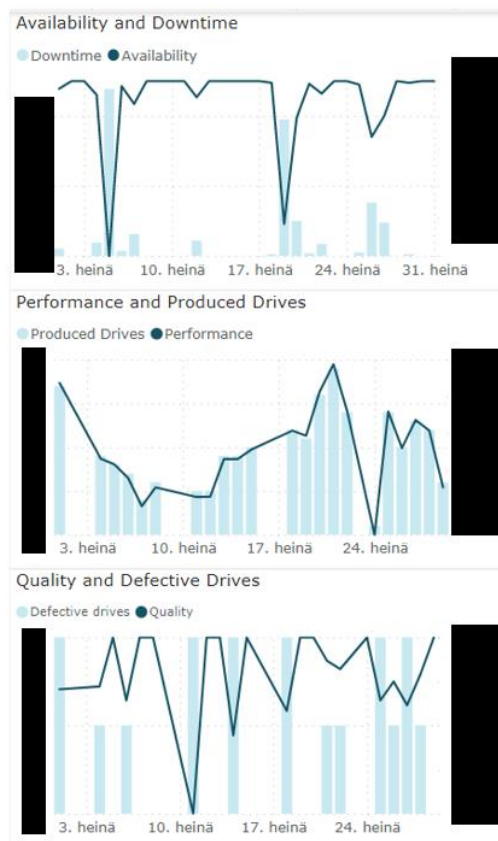


Figure 20 Updated charts of availability, performance & quality

Feedback 2, changing the visuals to month level from day level, was not applied to the report. The OEE calculations were unfeasible when changed to month

level. Feedback 3, changing the green target area to a constant target line, was applied to improve the usage of the report. In Power BI, only one target area could be created for a line. The two target areas were managed to include in the chart by creating a dummy OEE line that was exactly the same as the real OEE line. But the value from the dummy line would show up in the tooltips alongside the real OEE value. Dummy line and the green target area were removed to keep the usage of tooltips cleaner. Data point markers were removed according to feedback 4. Updated OEE chart is visible on figure 21.

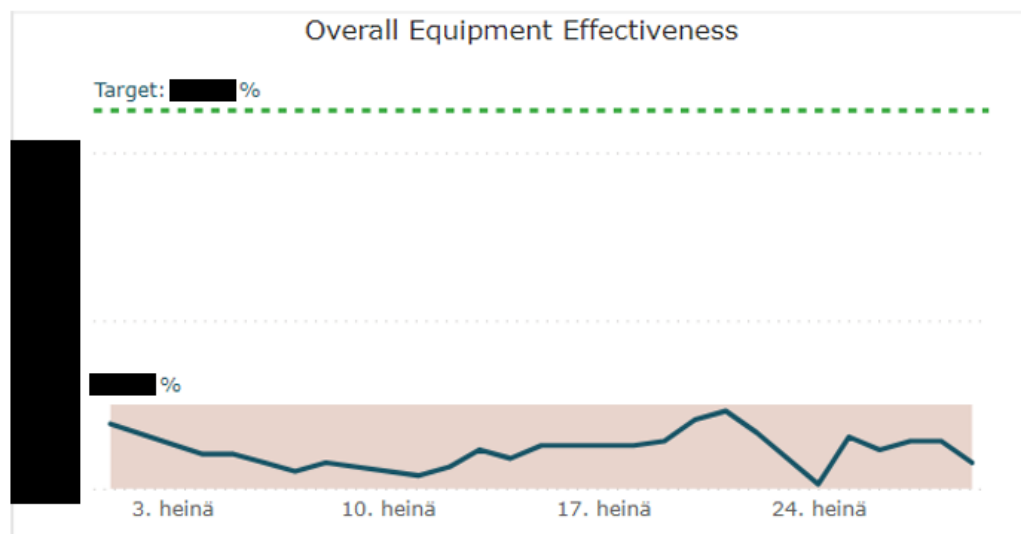


Figure 21 Updated overall equipment effectiveness chart

Lastly, according to feedback 5, the heading is inserted to the report. For the final version of the report some visual changes are applied, and the month names are switched to month numbers in the filter option.

6.3 Final proposal

Here, in figure 22, the final version of the report is presented. This version is handed in to ABB as an outcome of this project and is presented to ABB employees in the final presentation.

7 Conclusion

Chapter “Conclusions” includes summary of the thesis and an analysis about the observations made while creating the outcome of the project with some ideas moving forward. Lastly, the project is compared to the objective and outcome to see if the requirements were met and did it answer to the challenge given by ABB.

7.1 Summary

The project started with meetings with the ABB contact person and other employees where the objective for this project was defined. The result was achieved, and the objective was decided and agreed on without complications.

The objective of this thesis project is to perform an overall equipment effectiveness calculation for the fastening robot in ACS880-11/31 & ACx580-31 - R8 & R6 assembly line. These calculations were performed in Microsoft Power BI and then visualized in a Power BI report. In the report there are other data, besides the overall equipment effectiveness values, visualized to offer added value to the users.

The project started with making the schedule and research plan to be followed during the project. The different stages of the project would be current state analysis, conceptual framework, initial proposal and validation respectively.

Information for the current state analysis was acquired with two interviews. These interviews were held with two ABB employees in Microsoft Teams. The first interview was about the data flow of the fastening robot and the second one was an overview of the production line where the fastening robot is located.

Conceptual framework consist of theory about five main topics: the relational model, SQL, star schema, overall equipment effectiveness and Microsoft Power BI. References used for this theory are listed after chapter seven. They are listed in numerical order in the order they are used in the thesis.

The initial proposal was then created on the base of the current state analysis and the conceptual framework. The initial proposal consisted of the overall equipment effectiveness calculations and the first version of the Power BI report.

Validation stage was done to receive constructive feedback on the proposal. The feedback was analysed and then implemented to the proposal to end up with more beneficial end product.

The most important outcome is the overall equipment effectiveness calculations and the Power BI report visualizing the results and other data of the fastening robot's activity. These can offer value in decision making and development of the assembly line. The current state analysis and the conceptual framework were performed to aide in the proposal building stage.

7.2 Findings and next step suggestions

During this project, findings and observations about the subject have been documented. Now these findings are listed and analysed. The findings are only about the data used and the Power BI report.

The fastening robot on the assembly line is not used to its full capacity at the moment. The other side of the line, R6 assembly, does not use the fastening robot yet. This affects the performance values, and thus the overall equipment effectiveness values, since the available working time per day that is used in the calculations is the same as it would be if the R6 line would be used. When the R6

line utilises the fastening robot, then the values for performance and overall equipment effectiveness are more reliable.

In the data used in the calculations, there are inaccurate data values. Especially in the throughput time and produced drives fields. This affects the performance, quality and overall equipment effectiveness values for the days these inaccurate values appear. The inaccurate values do not affect the building of the report nor the functionality, but the values shown in the report. There is no risk in this issue if the inaccurate values are identified and ignored when using the report.

At this state the functionality of the report does not allow the user to examine the values on month level for all the charts. ABB employees do not have experience to use and get value out of a report like this, where overall equipment values and data related to the values are presented. With the values being on day level and filtered by month, it can be difficult to perceive the bigger picture the data shows. The overall equipment effectiveness chart is not possible to be presented at month level but with the charts of availability, performance and quality it is possible.

The first suggestion on how to proceed with this report would be to have the data available in a cloud storage. There are already plans for this to happen in the first quarter of 2023. When the report uses a cloud storage for the data, it can present real-time data in the visualizations. When this is achieved there is no need to manually import the data to the report.

Second suggestion is to modify the calculations in a way that the report can be used on a month level. Getting used to examine the data the report presents should be easier that way. Presenting a whole year in monthly values with the report would offer a different perspective of the data.

Lastly, when the cloud implementation is completed, creating calculations for all the visualizations in the report to present values for the last 30 days would be a good addition. Having the possibility to look at the data of the whole year and

then drilling down to one specific month if there is a need to have a more detailed look of the values of one specific month. Then also having the last 30 days available for the most up-to-date data. The last 30 days can then be compared to other months of the year to have insight whether the current situation is favourable or not favourable.

7.3 Evaluation

In the beginning of the project the objective was defined to have a clear goal what to achieve. Then a research plan and a schedule were created to ensure the completion of this project. These were followed during the project. There was slight delay on the project schedule caused by problems with getting access to the data and the creation of the initial proposal taking longer than expected. In the end, these delays had little effect on finishing the project on time.

The outcomes agreed with ABB at the start of the project were met. The outcomes include four different parts, those being, analysis of the current state, overall equipment effectiveness calculation, visualization of the data and the final presentation. All these were provided to ABB. The outcomes were agreed on to offer ABB a tool to monitor the activity of the fastening robot. The report provided will do that, at least to some extent.

More time could have been spent on the report to improve the usability of it. Having the option to view the data on month level would have made the report more complete. However, the schedule of this project did not allow this.

For chapters three and four versatile references were used. The sources for the references were credible and those are listed at the end of this thesis. The references are mentioned in the text and are listed in the reference list, in numerical order in the order they are used in the text.

There are given suggestions of next steps to follow after the report is implemented to use inside ABB. Three suggestions that are realistic and achievable. When followed up correctly, those can offer more value to the use of the report.

7.4 Closing words

Thesis projects have specific and predefined objective and outcome. This project produced a particular solution to ABB that matches the need that was the reason this thesis project was completed. This solution can be utilized, and it should help the company to get a comprehension on how to get value out of a report of this kind.

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Appendix 1: Notes of CSA interview – System Development Specialist

Interviewee	System Development Specialist
Date & Time	30.9.2022 30min
Interview type	Teams interview

Question
Could you introduce yourself and your role at the company?
How does the data end up from the fastening robot to the SQL database where it is stored?
Could you describe the dataflow to help me create a roadmap of it?
Are there any existing illustrations about the dataflow that can be used for this thesis?
What kind of messages appear in to SAP about the assembly?
How is the data extracted from the PC?
Who has created the SQL database where the data is stored, and does it have all the data the robot collects?

Appendix 2: Notes of CSA interview – Advanced Analytics Specialist

Interviewee	Advanced Analytics Specialist
Date & Time	4.10.2022 25min
Interview type	Teams interview

Question
Could you introduce yourself and your role at the company?
What kind of drives does the assembly line, where the fastening robot is located, produce?
What is the voltage range of these drives?
How many drives are made per day?
What is the throughput time of one drive?
What is the fastening robots' part of this?
Of the whole Drive Products daily volume, how many percent is produced on this line?
When is the R6 line going to start using the fastening robot?