Data-driven Inventory Management

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Abstract

The explosion in the availability and accessibility of data provides opportunities to improve inventory management within a company. Reviewed studies into the topic of inventory management demonstrate that enhancing an organization's inventory management can significantly improve the quality of the outcome of business performance. The literature review confirmed that data analytics can be used to enhance information extraction and decision-making in inventory management. A design process was developed to outline the phases that were followed in this graduation project. The design process of this graduation project consists of five phases: (1) Empathise, (2) Ideate, (3) Converge, (4) Realize, and (5) Evaluate. Stakeholders were actively involved in each of these phases. In this research, a tool was developed for analysing and visualizing data in order to derive value from inventory data. Such a system is expected to enhance the effectiveness and efficiency of handling inventory. In addition, it allows automating several processes within a company. The proposed tool was implemented and evaluated at AEMICS, an electronics design and manufacturing company.

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List of Abbreviations

API	Application Programming Interface
ASIC	Application-specific integrated circuit
BDA	Big data analytics
BOM	Bill of materials
CUE	Components model of User Experience
CEO	Chief executive officer
ERP	Enterprise resource planning
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IoT	Internet of Things
meCUE	Modular evaluation of key Components of User Experience
MFPN	Manufacturing part number
PCBA	Printed Circuit Board Assembly.
QR	Quick Response
REST	Representational State Transfer
RFID	Radio-frequency identification
RMA	Return material authorization
R&D	Research & Development
SMD	Surface-mount device
SME	Surface-mount equipment
SMTP	Simple Mail Transfer Protocol
SQL	Structured Query Language
UML	Unified Modelling Language
URL	Uniform Resource Locator
URI	Uniform resource identifier
UTAUT	Unified Theory of Acceptance and Use of Technology
UX	User experience
VAT	Value Added Tax

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Introduction

The main objective of this thesis is to develop a tool for analysing and visualizing data to derive value from the inventory data available at AEMICS. Such a system is expected to enhance the effectiveness and efficiency of handling inventory. In addition, it allows automating several processes within a company. The proposed tool will be implemented and evaluated at AEMICS, an electronics design and manufacturing company. This chapter will begin with background information on using data to enhance inventory management, followed by a description of the company at which the study will be conducted, then define objectives, formulate research questions, and eventually provide a report outline.

1.1 BACKGROUND

The number of devices that generate data streams has increased tremendously in comparison to a decade ago. Technologies such as ubiquitous-sensing mobile devices, aerial sensory techniques, cameras, microphones, Internet of Things (IoT) technologies, and wireless sensor networks have heavily contributed to this development [1]. Manufacturing firms are constantly trying to draw insights from big data to improve internal decision-making and operational efficiency [2]. Businesses have utilized the explosion in the availability and accessibility of data to gather insights that would improve decision-making within their company [3], [4].

The scope of this graduation project is narrowed to the use of big data in the context of inventory management. Inventory management involves planning, directing, and controlling inventory within a business [5]. Previous research has shown that big data analytics (BDA) can be applied to optimize knowledge extraction and decision-making in inventory management [6]. Advanced machine learning and optimization algorithms can be used to exploit observed patterns, associations, and interactions between data and decisions [7]. Furthermore, Bertsimas et al. [8] reported that big data can be used to make better inventory management decisions and have a competitive advantage. Thus, big data appears to be a promising technology that has the potential to transform inventory management significantly.

1.2 INTRODUCTION TO AEMICS

AEMICS is an electronics design and manufacturing company based in Oldenzaal. It supplies its customers with the research, development, and manufacturing of complex and advanced electronics. Ever since its founding in 1996, the company has worked together with a wide variety of clients on product development. AEMICS began with the development of application-specific integrated circuits (ASICs), which are integrated circuit chips that are customized for a particular use. ASICs and embedded sensors are used in a wide range of signal processing applications. AEMICS customers are worldwide and active in medical, industrial, and defence markets.

There are, in total, about twenty people employed at AEMICS. AEMICS has two departments: engineering and manufacturing. Both teams use the Scrum development methodology, which is an Agile framework that is designed to deliver value to the customer throughout the development of the project. Scrum is used in software development as well as in the manufacturing process of electronics. The engineering department consists of hardware, software, and mechanical engineers. Product development, testing, and applied research are among their responsibilities. The manufacturing department deals with circuit boards, modules and cables, programming, and testing.

AEMICS created its own enterprise resource planning (ERP) system for collecting, storing, managing, and interpreting data from a variety of their business activities. The inventory of AEMICS consists of a wide range of electronic components that are received from various distributors. All components and products have a unique serial number in the form of a barcode. In this way, every step of the manufacturing process can be tracked, and any deviations will be noted. Furthermore, serial numbers are also used to keep track of test results. The ERP system also stores the bill of materials (BOM) that was used to manufacture the product and which firmware version was used to program it this way. In addition, employees use the ERP system to record their activities, providing insight into the amount of time spent on each activity. Finally, the ERP system shows each component's current stock.

1.3 PROBLEM STATEMENT

Even though many businesses recognize the value of big data, very few have yet seen the impact of it. According to a survey performed by the Economist Intelligence Unit (EIU), although 70% of business executives recognize the importance of sales and marketing analytics, only 2% believe their analytics have had a positive effect on their company [9]. Similarly, McAfee and Brynjolfsson [10] reported that businesses collect more data than they know what to do with it. Many organizations are overwhelmed with data and lack the resources necessary to extract value from it. Collecting and storing big data does not create business value; value is created only when the data is analysed and acted on [11]. Moreover, data analysis has become more challenging; around 80% of data is now unstructured or semi-structured, making it difficult to analyse using traditional methods [12].

As discussed in the previous paragraph, extracting maximum value from collected data can be a difficult task for businesses and it comes with many challenges. AEMICS is now confronted with these challenges as well. Currently, most data collected by AEMICS does not generate business value. AEMICS is busy gathering data, however, they currently perform limited data analysis, therefore the organization is unable to take full benefit of the available data. If the available data is analysed and acted on, it has the potential to have a significant impact on the company. For example, inventory data might be used to provide triggers when a component is about to run out of stock, or machine data may be used to gain insight into component loss during manufacturing.

1.4 OBJECTIVES

Section 1.3 affirms the need for a tool for analysing and visualizing data in order to derive value from the data available at AEMICS. Such a system could enhance the effectiveness and efficiency of inventory management at AEMICS. Effectiveness could be defined in this context as producing the intended or expected result [13]. Efficiency means being able to accomplish something with the least waste of time and effort [14]. The aim of this thesis is therefore to create a tool that can analyse and visualize data to provide useful insights to stakeholders.

1.5 RESEARCH QUESTIONS

This bachelor thesis will deal with the following research question: *In what way can data analytics be used to improve inventory management at AEMICS?* To address the main research question, three sub-questions have been formulated:

1) What does the current situation look like at AEMICS with respect to inventory management?
2) Which architecture style is suitable to be used in combination with the current system at AEMICS?
3) How can data visualizations be designed that support employees at AEMICS making insightful interpretations and informed decisions?

1.6 REPORT OUTLINE

The remainder of this paper is structured as follows. Chapter 2 will present background information related to the project, including a literature review and a description of the current situation at AEMICS. Chapter 3 will describe the methodology used in this project. Chapter 4 covers the results of the first phase of the design process, the Empathise phase. The findings of the Ideation process are then discussed in Chapter 5. Following that, in Chapter 6, the ideas that arose during the Ideation phase will be narrowed down to a single concept. Chapter 7 will go through the system design of the concept that emerged from the Converge phase. The outcomes of the Realize phase are then discussed in Chapter 8. Chapter 9 describes the Evaluation phase, in which the application will be evaluated. Finally, the conclusion will answer the research question and some recommendations will be given for future research.

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Background

The findings as mentioned in Chapter 1 have emphasized the value of developing tools that can analyse data generated by businesses, which in turn, provide actionable insights. To create such a tool, we must first understand big data sources and explore the possibilities of using BDA for inventory management. Therefore, the objective of the literature review in Section 2.1 is to identify inventory-related sources of big data and to highlight opportunities for the utilization of BDA in inventory management. Thereafter, AEMICS' current inventory management, as well as its system architecture and ERP system, are described.

2.1 LITERATURE REVIEW

2.1.1 Inventory management objectives and difficulties

There are several objectives related to inventory management. The main purpose of inventory management is to have the right amount of inventory in the right place at the right time [15], [16]. Similarly, Chan et al. [17] state that the purpose of inventory management is to ensure the availability of resources in an organization. Song et al. [18] state that inventory management is essential to maximize cost productivity by minimizing overall inventory ordering, holding, and shortage costs. Reid et al. [5] have argued that inventory management aims to provide the desired level of customer support, allow for cost-effective operations, and further minimize inventory costs.

Although several sources have vouched for the effectiveness of proper inventory management, there are difficulties that companies face when it comes to inventory management. According to Chan et al. [17], the most common issues are underproduction, overproduction, stockout situations, raw material supply delays, and inventory discrepancies. As a result, stockouts lead to lost sales and disruptions in production [19]. Moreover, Inegbedion et al. [20] pointed out that understocking, overstocking, attendant shortage costs, and holding costs all have a significant adverse effect on an organization's profitability.

In summary, effective inventory management is important for organizations to ensure that the right amount of inventory is in the right place at the right time. Improper inventory management can result in several issues such as underproduction, overproduction, stockouts, delivery delays, and inventory discrepancies. Therefore, it is intriguing to look at how big data can be used to minimize the difficulties related to inventory management.

2.1.2 Definitions of big data and BDA

Big data definitions have evolved rapidly, and formally there is no single definition adopted for the term big data. Laney [21] proposed a framework that explained an explosion in data based on *Volume* (the large amount of data considered), *Variety* (the huge variety of data sources and formats), and *Velocity* (the frequency or speed of data generation). The Three V's have emerged as a common framework to describe big data. Gartner [22] defines big data as the following:

> *"High-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making."*

Organizations need efficient processes to turn high volumes of fast-moving and diverse data into meaningful insights. Analytics refers to techniques used to analyse and acquire intelligence from big data [23]. BDA refers to a set of procedures and statistical models to extract information from a large variety of data sets [24]. Krishnan [25] states that:

> *"Big data analytics can be defined as the combination of traditional analytics and data mining techniques along with large volumes of data to create a foundational platform to analyse, model, and predict the behaviour of customers, markets, products, services,*

and the competition, thereby enabling an outcomes-based strategy precisely tailored to meet the needs of the enterprise for that market and customer segment."

BDA can be categorized into three distinct methods: descriptive, predictive, and prescriptive analytics. *Descriptive analytics* deals with the question of what has happened, what is happening, and why it is happening [6]. It attempts to identify problems and opportunities within existing processes and functions [26]. *Predictive analytics* investigates data patterns using mathematics, modelling, and programming to determine what will happen or is expected to happen in the future [6]. *Prescriptive analytics* describes the use of data and statistical algorithms to decide and evaluate alternate decisions involving high-volume, high-complexity priorities and specifications [26].

In short, BDA turns large volumes of fast-moving and diverse types of big data into meaningful insights. The three main types - descriptive, predictive, and prescriptive - provide several ways to enhance inventory management, as discussed later in this review.

2.1.3 Big data sources

The bulk of big data generated in firms comes from a wide range of technological sources. Rozados and Tjahjono [27] identified mainstream sources of big data across the supply chain. They classified those data sources in a taxonomy according to their features in the Three V's framework as shown in Figure 1. Rozados and Tjahjono [27] differentiate between core transactional data, internal systems data, and other data sources.

KPMG [28] mentions five main sources of big data in supply chains, similar to the mainstream sources identified by Rozados and Tjahjono [27]. First of all, the authors of KPMG claim that RFID data and GPS data will help in real-time inventory positioning and warehousing. They also state that one of the key enablers of market forecasting and consumer behaviour analysis is the point-of-sale data. Furthermore, supplier data will help manufacturers in monitoring supplier performance and managing risk and capacity. Finally, they point out that manufacturing sensor data would assist in the identification of output bottlenecks and imminent system faults, thus preventing expensive machine downtime.

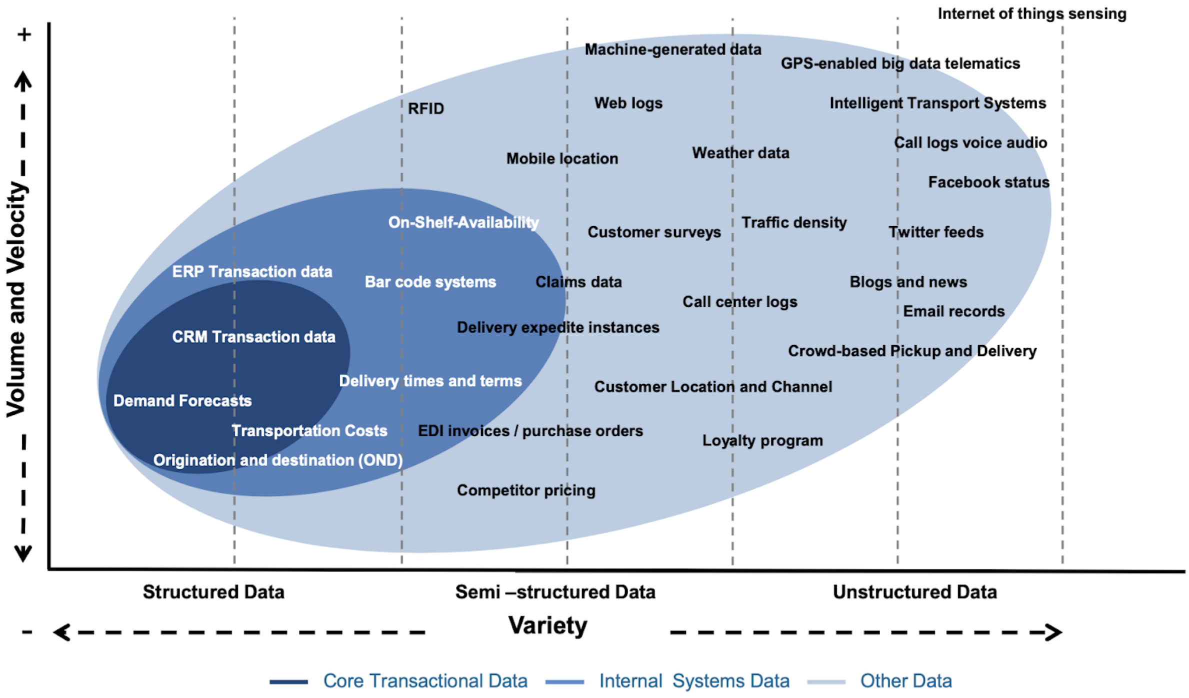

Figure 1. Supply chain big data sources. Adapted from **[27]**

Both Cohen [7] and Fernández-Caramés et al. [29] pointed out the exponential growth of Internet of Things devices has resulted in the generation of a huge volume of data. This is supported by others, for instance by Rozados and Tjahjono [27] who reported that nowadays a huge amount of data is generated through the use of numerous smart devices, such as Internet of Things (IoT) devices, extended sensors, material handling, and packaging systems, position sensors for on-shelf availability. Similarly, Cohen [7] states that smart devices can produce lots of data about current operating conditions and real-time performance of products. Moreover, Fernández-Caramés et al. [29] demonstrate the technological evolution of labels or tags added to inventory items. They address various identification technologies, including barcodes, QR codes, RFID tags, RFID sensor tags, and smart labels. Sharma et al. [16] also state that barcodes and RFID tags are the two most common ways to set up an automatic inventory management system for interpreting and recording inventory data.

Overall, previous research has shown that the rapid growth of smart sensors has resulted in a significant rise in the amount of data produced and processed. Big data sources related to inventory management include barcodes, RFID tags, manufacturing sensors, position sensors for on-shelf availability. IoT systems integrate big data sources with the Internet to create an extensive network that can be used to improve inventory management. The extensive network of big data sources creates numerous opportunities to enhance the efficiency of inventory management, which is discussed in the following section.

2.1.4 Opportunities of big data in inventory management

Regarding the use of BDA for inventory management, several opportunities can be pointed out. First of all, big data can assist companies in developing inventory optimization technologies, responding to changing consumer demands, lowering inventory costs, obtaining a holistic view of inventory levels, optimizing the flow and storage of inventory, and reducing safety stock [26]. This is supported by Sharma et al. [16], who report that through processing big data in real-time, the root causes of errors, problems, and flaws can be quickly identified. In addition, Sharma et al. [16] also argue that BDA contributes to understanding employee engagement, improved procuring decisions, and the minimization of errors. Tiwari et al. [6] complement this by demonstrating how analytics can be used to improve supply chain production, scheduling, and inventory handling. For instance, descriptive analytics may be used to display total stock in the current inventory, average consumer purchases, and year-to-year changes in sales [6].

In addition, BDA can also help businesses predict several factors in order to enhance inventory management. Wang et al. [26] emphasized the potential of statistical forecasting techniques to help in effectively predicting inventory needs and responding to changing consumer demands. This is supported by other researchers, for instance, by Popovič et al. [2] who pointed out BDA's ability to predict and improve process performance. This ability is said to benefit organizations through cost savings, improved operations planning, appropriate inventory levels, better labour force organization, and waste elimination, all while enhancing operations effectiveness and customer service. According to Roßmann et al. [30], BDA is expected to substantially improve the accuracy of demand forecasts. As a result, more accurate demand forecasting leads to lower inventory levels and more accurate safety stock levels [30]. Moreover, Tiwari et al. [6] state that predictive analytics can help to forecast consumer behaviour, and spending habits to identify trends in sales activities.

2.1.5 Conclusion

This paper attempts to identify sources of big data relating to inventory and to point out several opportunities regarding the use of BDA for inventory management. Reviewed studies into the topic of inventory management demonstrate that enhancing an organization's inventory management can significantly improve the quality of the outcome of business performance. The studies reviewed in this paper claim that BDA can help organizations face several challenges with inventory management, such as underproduction, overproduction, stockout situations, raw material supply delays, and inventory discrepancies. Indications in the examined literature state that there are several possibilities for applying BDA in inventory management. One of the opportunities is to use forecasting techniques to predict inventory needs, consumer behaviour, and spending habits. These predictions can assist in identifying market trends as well as determining where and how much inventory to buy. BDA could also detect potential supply disruptions early on. Moreover, BDA may be used to display total stock in an inventory, the average consumer purchases, and year-to-year changes in sales. In short, big data appears to be a promising technology that has the potential to drastically transform inventory management for the better. BDA can be used to enhance information extraction and decision-making in inventory management.

Although it has been implied that the use of big data can improve inventory management in organizations, further research is needed. Previous research has emphasized the importance of developing tools that can analyse and provide meaningful insights from big data. Future research should look at how BDA is used in various industries, as the use of BDA in inventory management is highly dependent on the type of company. More knowledge should be gathered on how machine learning and optimization algorithms can be used in inventory management to leverage observed patterns, connections, and interactions. Other focus areas for future research are case studies or real-world implementations of BDA in inventory management. This will show whether the advantages of using BDA in inventory management are realized in practice, as well as what issues arise when BDA is used in organizations. To conclude, the literature review confirms the necessity for data analysis and visualization tools in order to extract value from the data available at AEMICS. The opportunities discovered throughout this review will be considered during this project.

2.2 CURRENT SITUATION AT AEMICS

2.2.1 Workflow

AEMICS develops its products, which can be purchased through the web shop. Aside from ordering a product from AEMICS's web shop, it is also possible to collaborate with AEMICS on the development and manufacturing of electronics. AEMICS develops products for clients based on their ideas and in close collaboration with them. The processes that AEMICS will carry out are determined by the preferences of the client. AEMICS offers support at all stages of the product life cycle, from prototype development through serial production. AEMICS may also create a proof-of-concept, which is the realization of a certain method or idea to demonstrate its feasibility.

After receiving a request for quotation, AEMICS will estimate the product costs, effort, and duration. Product costs are the expenses incurred in manufacturing a product. Direct material costs, which are the expenses of raw materials used directly in the production, are included in product costs. Direct labour costs are also factored into the product costs. The direct labour costs include the salaries, benefits, and insurance paid to employees who are directly involved in the manufacturing process. Moreover, manufacturing overhead costs are also included in the product costs. Manufacturing overhead expenses are direct factory-related costs spent during the production of a product, such as the cost of machinery and the cost of operating the machinery.

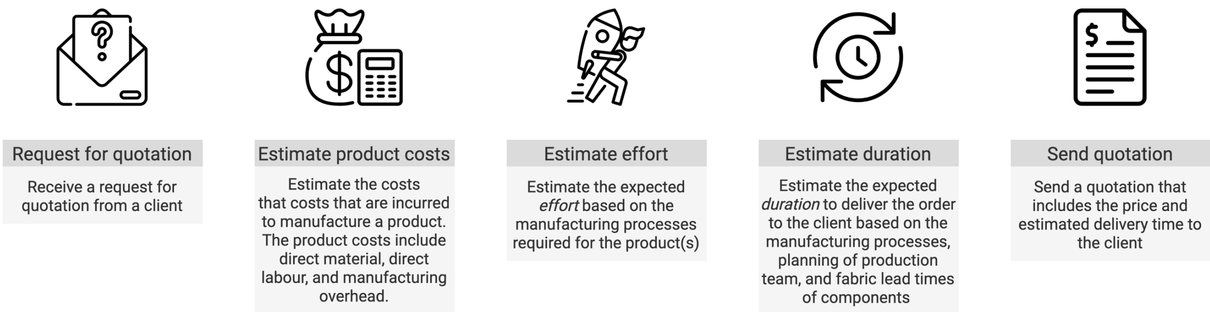

Figure 2. Workflow after receiving a request for quotation

Moreover, the amount of effort (in hours) required to build a product will be anticipated to establish a quote. This estimate is typically determined by taking into consideration the product's features as well as similar projects in the past for which actual effort is known. The expected time to complete each stage in the production process will also be considered.

Finally, the projected duration will be determined to provide the client with an approximate delivery time. The duration is determined by the complexity of the production and the amount of time needed to manufacture the product. Furthermore, when the manufacturing process may begin is determined by the production team's planning. The lead times related to the components needed in the manufacture of the product also have an impact on the duration. The lead time of a component is the latency between the placement of an order and actual delivery of the component. It should be considered whether all components can be obtained from suppliers. Figure 2 depicts an overview of the workflow as described in this section.

2.2.2 Manufacturing process

AEMICS is specialized in the design and manufacturing of advanced electronic products. At the heart of these electronics is the printed circuit board, or PCB, which is a board that connects electronic components. A PCB is a thin baseboard made of insulating material (such as resin-bonded paper or fiberglass) with an even thinner layer of copper on one or both surfaces [31]. If copper is only present on one surface, it is referred to as a single-sided PCB [32]. When copper is present on both surfaces, the board is called a double-sided PCB, and it has a top and bottom layer on which components can be mounted [33].

The copper on the surface of a PCB has been printed as a circuit, allowing components on the PCB to be soldered to the copper and therefore be connected to other components [32]. Soldering means joining two pieces of metal in what is called a solder joint [34]. A pad is a small surface of copper on a printed circuit board that allows soldering the component to the board [35]. Typically, two types of PCB pads are used: soldered surface-mount pads and soldered through-hole pads. A surface mount pad is a square or rectangular copper region that is used for surface-mount component attachment [36]. The size and shape of the pad are determined by the component attached to it [36]. Through-hole pads are intended for introducing the pins of the components, so they can be soldered from the opposite side from which the component was inserted [37].

As indicated in Figure 3, a solder mask is on top of the copper layer. A PCB has traces, which are continuous paths of copper on the board [35]. The solder mask prevents the copper traces from coming into touch with other conductive materials, which could result in a short circuit [31].

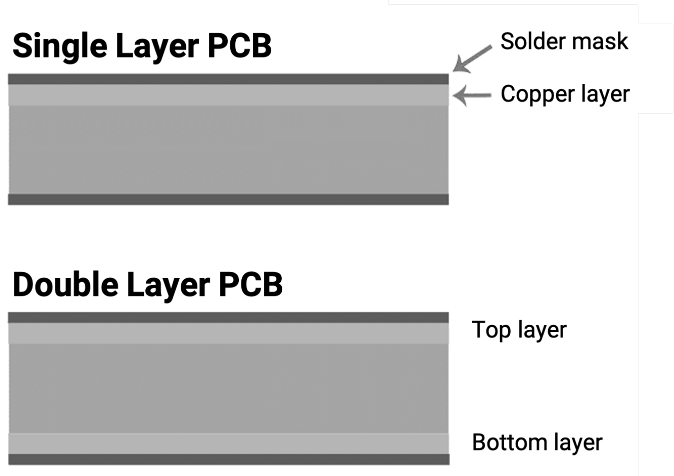

Figure 3. Layout of a printed circuit board (PCB). Adapted from **[38]**

Figure 4 depicts an overview of the steps of placing components on a PCB. The first step in PCB assembly is to apply solder paste to the surface mount pads on a PCB before placing the components. Solder paste is used to connect components to pads on the board. To apply paste to specific parts of a PCB, a stencil with a bunch of holes in it can be utilized. The process of using a stencil to apply solder paste to pads on a bare PCB is referred to as solder paste stencilling [39].

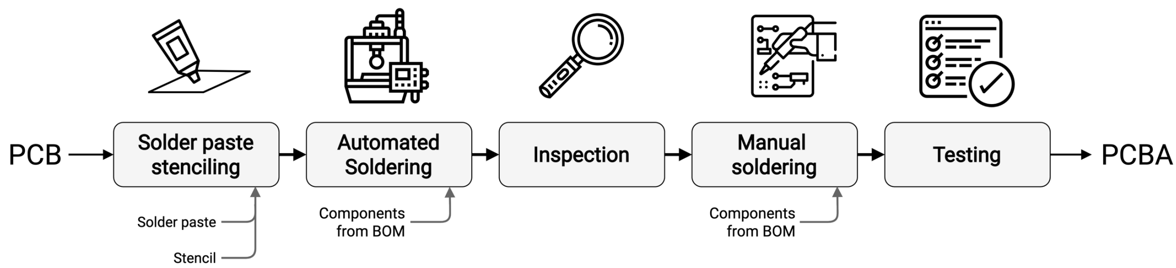

Figure 4. Production processes

The next step in the assembly process is placing the components on the board. This is often done with an automated pick-and-place because it is faster and more accurate than manual placement. AEMICS uses a pick-and-place machine from Mycronic to place electronic components, like capacitors, resistors, integrated circuits, onto printed circuit boards. After the pick-and-place machine is finished, an inspection will be performed to ensure that the component placement is correct. It is occasionally necessary to manually install components on a PCB, which is known as hand soldering. Hand soldering will be needed for components with unique needs, for maintenance, or when the pick-and-place machine cannot be used. Finally, the product can be tested once all the electronic components have been placed on the PCB.

The production process sheet consists of a list of all steps taken in the process to manufacture a particular product. A bill-of-materials (BOM) is related to the production process sheet, which comprises the components required to complete the steps in the production process sheet.

2.2.3 Current inventory management at AEMICS

The inventory of AEMICS consists of a wide range of electronic components that are received from various distributors. Components can be shipped from a distributor in a variety of packing formats. Most distributors offer the same components in a variety of packaging to support different pick-and-place loading preferences. Each packaging form has advantages, and the optimal one depends on the circumstances. The most used packaging forms are cut tape, reel, tray, tube and batch. Each of these packing types is referred to as a carrier since it 'carries' components.

Both cut tapes and reels are made of a tape on which components are adhered. Cut tape distributes components in short cuts of tape, whereas a reel contains a long, continuous, tape wrapped up on a reel. Trays and tubes are made up of discrete compartments where components are placed. Components can also be acquired in bulk, which implies they are loose parts that are packaged in a (plastic) bag.

AEMICS uses barcodes that are associated with a particular identifier to label their inventory items. The ERP system enables employees to quickly print bar code stickers, which are then adhered to an inventory item. If the production team uses a carrier, it is either used in hand assemblage or placed in the pick-and-place machine. The pick-and-place machine can keep track of how many components are used and store this information in its database. When components from a carrier are used for hand assemblage, the production team member must scan the carrier components that are used. After scanning a component's barcode, the inventory level of that component will be automatically updated. As a result, the system of AEMICS can keep track of the existing stock of components in the warehouse, which is shown in the ERP system.

The barcode stickers attached to inventory items come in either green or white. The components with green stickers are Kanban items, while the items with white stickers are order-related components. AEMICS uses the term Kanban to refer to inventory items that are frequently used. Each Kanban component has its own minimum threshold, and the current stock should never fall below it. If a reel marked with a green sticker (Kanban) is empty, it is placed in the Kanban bin. Every week, the purchaser takes the Kanban bin and scans all of the barcodes on the reels in it. The purchaser orders components based on this information. The inventory items with white stickers are order-related items. Those components are only purchased when a client of AEMICS places an order that requires that component.

In short, the procurement is divided into Kanban orders and order-based purchases. Kanban orders are placed to ensure that each Kanban component's stock is greater than its minimum threshold. Order-based transactions are made in response to a client's order; all of the components required for that order are included in the order-based purchase.

2.2.4 Architecture

AEMICS, as previously reported, developed its own ERP system. AEMICS decided to break the system into microservices that can be distributed independently and communicate with one another, instead of putting all of the code into a single application. Furthermore, a REST API architectural style was implemented as an application program interface (API) that accesses and uses data through HTTP requests. AEMICS also decided to split the database such that each microservice has its own database and maintains its piece of data, rather than a single massive database holding all information.

As illustrated in Figure 5, there is a Mycronic worker which has a PostgreSQL and a MySQL database. Mycronic refers to the name of the pick-and-place machine that is used by AEMICS to place electronic components, like capacitors, resistors, integrated circuits, onto printed circuit boards. The Mycronic worker is responsible for caching and exchanging information related to the carriers. The Distributor worker is a microservice that collects data from distributors using their API’s. It retrieves for products the product id, current stock, and price from the distributor. Finally, the Notification worker is responsible for tasks related to the SMTP server (mail) and the chat used for employee communication.

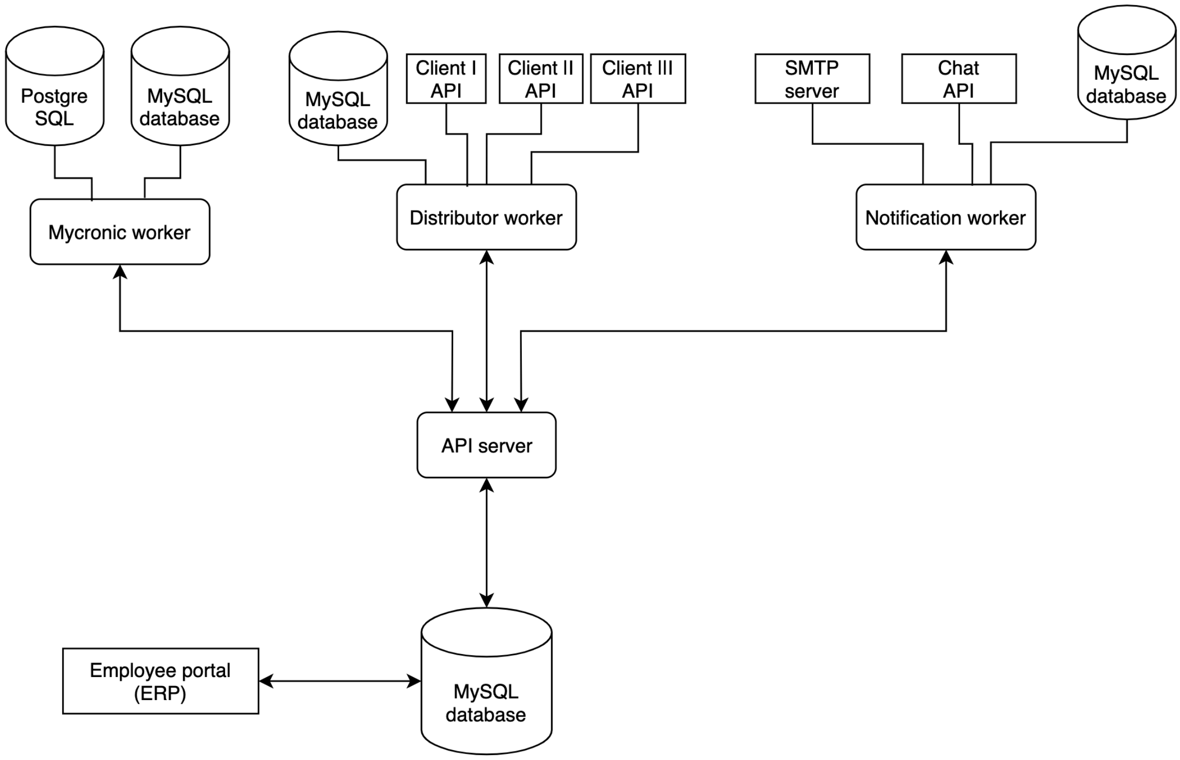

Figure 5. System architecture with microservices

The AEMICS API server and the ERP both communicate with the same MySQL database. As seen in Figure 6, SQLAlchemy is used to communicate with the MySQL database. SQLAlchemy is an open-source SQL toolkit and object-relational mapper (ORM) for Python, and it is built for fast and high-performance database access. To make the system run faster, both the ERP and the AEMICS API use a Redis cache containing previously processed data. When something in the MySQL database changes, RabbitMQ keeps track of it so that it can be updated or invalidated in the Redis caches. Furthermore, the ERP uses Python on the server side with the Pyramid framework to fill Mako templates with data, and as a result, HTML is created from Python code.

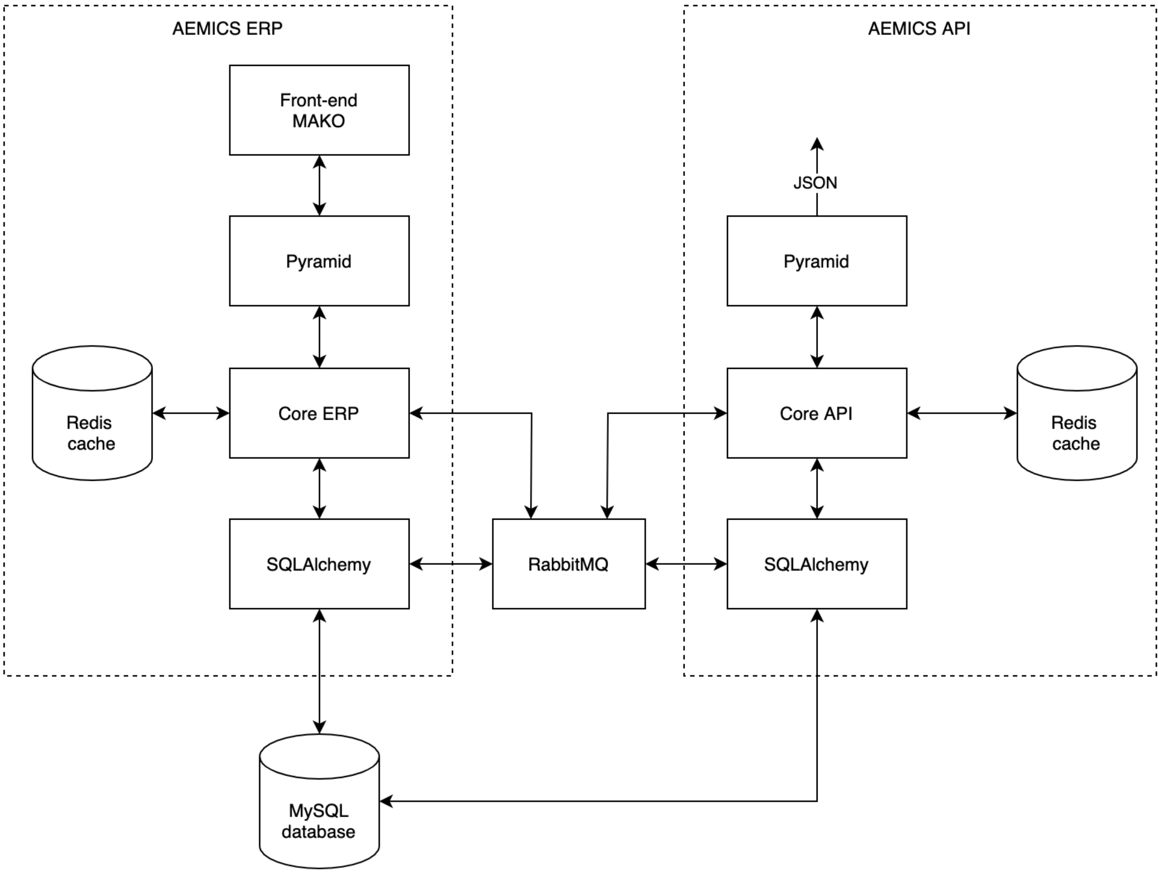

Figure 6. Current system architecture

2.2.5 ERP system

Appendix A contains screenshots of a part of the ERP system to demonstrate how it looks. The top bar contains six main tabs: Components, Products, Orders, Projects, Planning, and Relations. When you click on a tab, its subtabs appear. Appendix B contains a table that explains the features of each subtab. Almost every item in the tables of the ERP system has an eight-digit unique identifier. The type is denoted by the first two digits of the identifier. The production process sheets, as shown in Appendix C, are an essential part of the ERP system. The manufacturing team follows a schedule that is comprised of production sheets. A production sheet includes the steps required to develop a product as well as the bill-of-materials (BOM). The bill of materials (BOM) is a list of the components required to manufacture the product.

Another useful feature of the ERP system is that it displays the existing stock of a part. Appendix D depicts the sidebar that appears when you press a component in the Components table. Since the pressed component is a Kanban item, the minimum threshold, in this case 20000 pieces, is displayed.

As stated previously, the production process sheet consists of a list of all steps taken in the process to manufacture a particular product. In a production process sheet, the same product is frequently manufactured many times. In other words, several instances of the product will be produced. For each instance, the completed steps will be recorded in the database. As a result, the number of instances that have finished a step can be determined for each step in the production process sheet. A stacked bar graph is displayed in ERP for each production process sheet to provide an overview of the progress. Figure 7 depicts a stacked bar graph of steps from a production process sheet. The number of instances that have completed the step is represented by the green bar. The red bar indicates the number of components that are discarded. The orange bar represents the number of instances that appeared to be incorrect. Finally, the blue bar shows how many instances still need to complete the step.

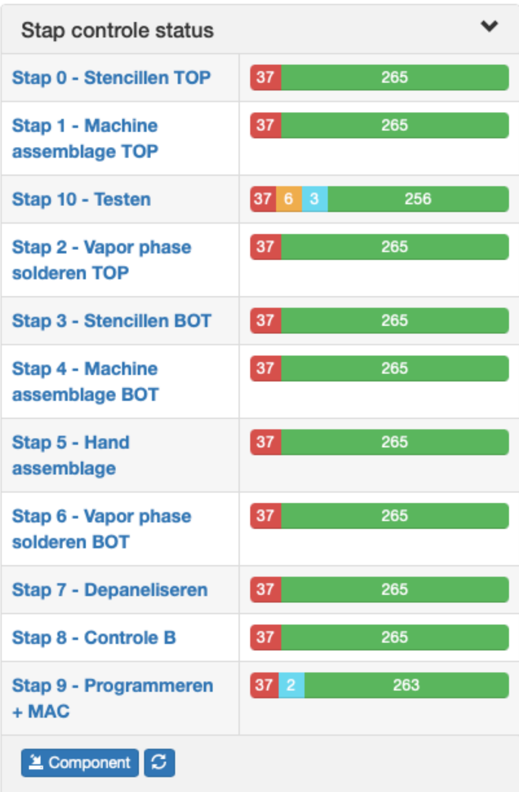

Figure 7. Screenshot of the steps related to a production process sheet

3

Methodology

This chapter will describe the design process adopted by this research. It provides an outline of the design phases that were followed in the project. The design process is divided into five phases: Empathise, Ideate, Converge, Realize, and Evaluate. Section 3.1 will provide background information for the design process. Following that, the methodology of each phase will be elaborated.

3.1 DESIGN PROCESS

The design process of this graduation project is a combination of phases from the Design Thinking model and the Creative Technology Design Process. The Design Thinking model proposed by Stanford's Hasso-Plattner Institute of Design consists of five stages: Empathise, Define, Ideate, Prototype, and Test [40]. Design thinking is used to solve ill-defined or unknown problems because it may reframe them in human-centric ways and focus on what matters most to users [41]. Mader and Eggink's [42] Creative Technology Design Process covers the phases of Ideation, Specification, Realization, and Evaluation. The complete Creative Technology Design Process is illustrated in Appendix E.

Figure 8 depicts the design process that will be employed in this graduation project. The design process is divided into five phases: (1) Empathise, (2) Ideate, (3) Converge, (4) Realize, and (5) Evaluate. Phase 1 is concerned with *empathizing* with the people for whom you are designing to comprehend their needs, thoughts, feelings, and motivations. Phase 2 is *ideating*, which entails generating many ideas and potential solutions. The ideas should then be collected, classified, refined, and narrowed down to the best concepts. This is referred to as *converging*, and it will occur during Phase 3. During Phase 4, the Scrum framework will be utilized to *realize* the product iteratively and incrementally. Finally, the extent to which the functional requirements are met will be assessed in Phase 5, and stakeholders will be consulted to *evaluate* their expectations. In the following sections, the methodology of each phase will be elaborated, and it will be explained how each phase was implemented in this project.

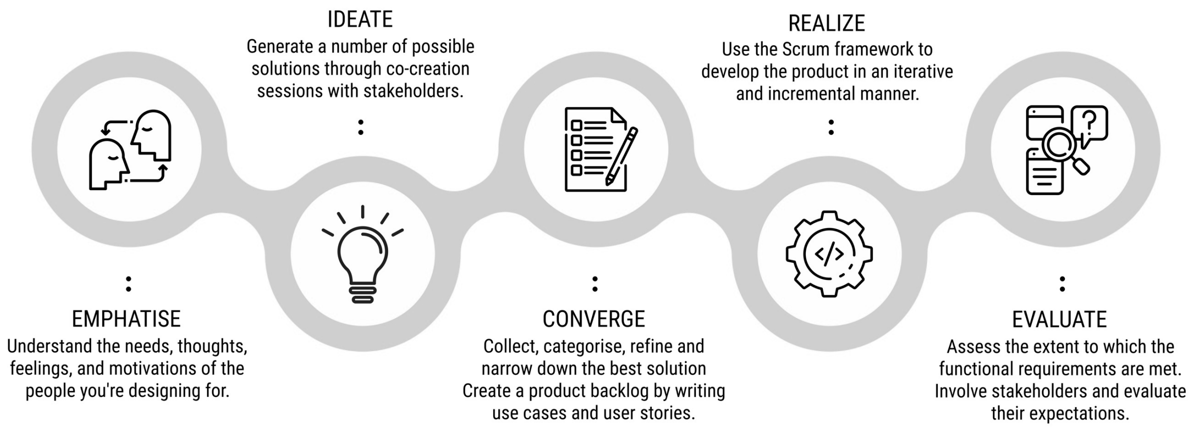

Figure 8. Overview of the design process

3.2 EMPHATISE

The first stage of the design process entails gaining empathy for the stakeholders to gain insights into their needs, thoughts, emotions, and motivations [43]. The aim of this stage is to increase the designer's comprehension of their target users, as well as to inform and inspire them to create a product that fits the user's needs [44]. Engaging with people reveals a lot about how they think and what values they have [40]. The initial step at this stage is to become immersed in the environment of the future users and internalizing the requirements of the users. The step requires time spent wandering around, becoming open-minded, and experiencing the user's world for a while [44].

The following paragraphs will describe how the Empathise phase will be implemented in this graduation project. After having been deeply immersed, group sessions with major stakeholders will be organized with the aim of discovering what the pain points and needs related to inventory are. In this context, a pain point is defined as a specific problem that AEMICS personnel are currently experiencing. The brain dumping technique will be used throughout the group sessions. The brain dump technique asks participants to individually write down their ideas on post-it notes and then share their ideas with the group [45]. Brain dumping can be seen as brainstorming written down. The benefit of brain dumping is that it allows for 'freethinking' and gives quiet employees a voice [46].

At the beginning of the group session, all the participants will be given sticky notes and will be asked to write down all the problems or issues that come to mind when they think about AEMICS' present inventory management. The goal of this question is to identify the problems that are encountered with the current inventory management system. After about ten minutes, the sticky notes will be gathered and stuck to a whiteboard so that everyone can see them. Participants have the option of responding to problems or telling stories. A 2x2 matrix will be drawn on the whiteboard, with the effort on the x-axis and the importance on the y-axis.

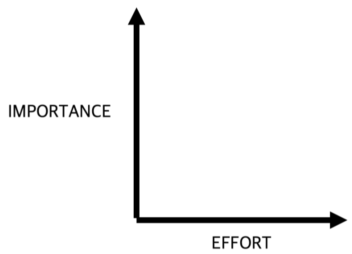

Figure 9. Matrix to arrange problems depending on their importance and estimated effort

Each sticky note is placed on the graph in a different location. A discussion will take place to determine where the problem should be placed on the graph. During the empathize stage, an effort is made to relate to the user and comprehend their situations, as well as why certain experiences are meaningful to them [44].

3.3 IDEATE

The purpose of the ideation phase is to generate many diverse ideas in order to examine a variety of possible solutions. The Ideation phase will be implemented in this project by co-creation sessions. Co-creation sessions with stakeholders are held during the ideation phase to gather knowledge and ideas from a wide range of people. Major stakeholders will be involved in the design process through co-creation sessions. The goal is to bring together stakeholders and encourage them to think about possible solutions. The brain dumping technique will be used during the co-creation sessions.

The co-creation session will start with an ice-breaker exercise to bring the group together, relieve any tension, and get everyone warmed up. The goal of the exercise is to come up with words or features that spring to mind when you envision a perfect inventory management system. All the information will be organized into a mind map on a whiteboard.

Following that, each participant will be asked to come up with ideas for tackling one or more of the inventory management difficulties currently being faced. Each idea should be written down on a separate sticky note. After about ten minutes, all the sticky notes are gathered and categorized.

3.4 CONVERGE

After the Ideation phase, it is time to collect, categorise, refine, and narrow down the best ideas. This is referred to as the 'convergent stage' and it is where ideas are assessed, compared, ranked, clustered, and dropped to put together a few great ideas to act on. The next part of this section will describe how the convergent stage was implemented in this project.

A matrix will be used as a mechanism for assessing the feasibility and potential of ideas. Feasibility is defined as "the possibility that can be made, done, or achieved, or is reasonable" [47]. In this context, an idea with great potential is one that possesses the necessary characteristics to become successful or valuable in the future. A 2x2 matrix will be drawn on the whiteboard, with the feasibility on the x-axis and the impact on the y-axis. The ideas will be assessed collectively by all participants at the end of the co-creation session. Each sticky note with an idea on it is placed on the graph in a different location. A discussion will take place between stakeholders to determine where the problem should be placed on the graph.

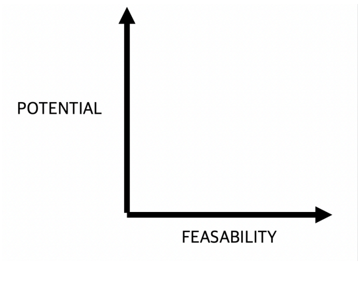

Figure 10. Matrix to arrange solutions depending on their feasibility and potential

The final step in this stage consists of writing user stories and use cases. User stories are a common way to represent requirements. A user story describes functionality that will be useful to a user, often using a simple template such as "As a ⟨role⟩, I want ⟨goal⟩, [so that ⟨benefit⟩]" [48]. In addition, use cases related to the user stories will be formulated. A use case is a description of a series of interactions between a system and one or more actors, where an actor can be either a user or another system [48]. Eventually, a product backlog will be created. The product backlog is a list of all the features that should be included in the product [48]. The initial product backlog includes the essential features that should be sufficient for the first sprint. As more information about the product and its users becomes available, the product backlog will expand and alter in the Realization phase.

3.5 REALIZE

The fifth stage, called Realize, entails creating the product based on the concept developed during the convergence phase. In this graduation project, the phases of the Scrum framework as shown in Figure 11 will be followed throughout the Realization phase. Scrum is both an iterative and an incremental process. The product is constructed and delivered in increments, with each increment representing a complete subset of functionality [48]. The Realization phase is divided into a series of three-week iterations called sprints. At the start of each sprint, the amount of work from the product backlog that can be accomplished during that sprint will be determined. The work that is expected to be completed during the sprint is added to a list called the sprint backlog.

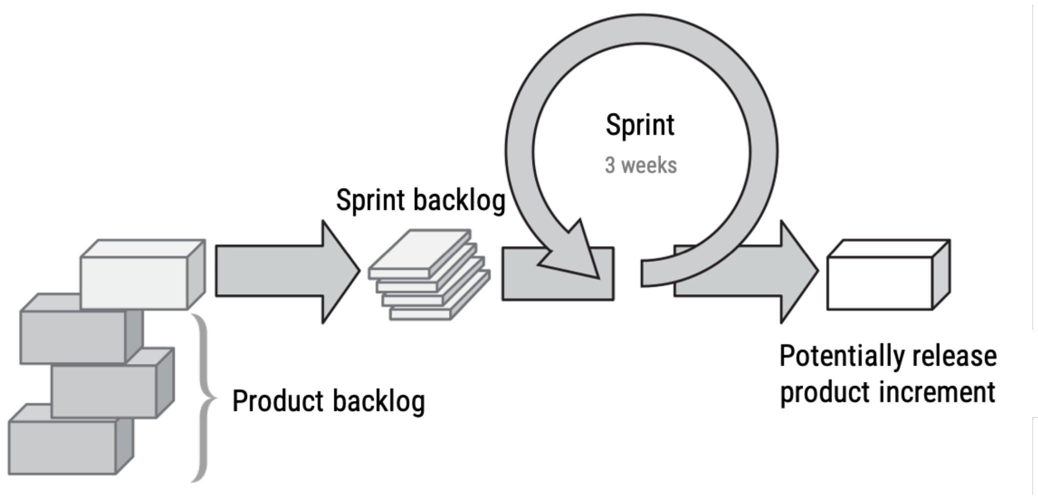

Figure 11. Graphical representation of the Scrum framework. Adapted from **[48]**.

3.6 EVALUATE

The final stage of the design process is the Evaluation phase, which entails evaluating the product. First, it is determined whether the functional requirements are satisfied in the final product. Following that, the stakeholders are involved, and the product is evaluated to see how well their expectations are met. The inventory analyzer may have a positive impact on AEMICS, but its success is dependent on acceptance and behavioural intent to use. The success of the application considerably depends on the acceptance of its actual users, i.e., AEMICS personnel. Therefore, it is important to explore the determinants of acceptance as well as the behavioural intention to use the inventory analyzer visualizations. To accomplish the aforementioned objective, the Unified Theory of Acceptance and Use of Technology (UTAUT) model [49] will be adopted during the evaluation phase. The UTAUT was chosen as the underlying theoretical framework since it considers the factors related to the prediction of technology acceptance and usage intention primarily in organizational contexts [50]. The UTAUT model has been slightly adapted to fit the context of this graduation project. The following two constructs were adopted from the UTAUT:

- Performance expectancy, defined as "the degree to which an individual believes that using the system will help him or her to attain gains in job performance" [49]
- Effort expectancy, defined as "the degree of ease associated with the use of the system" [49]

Another goal of this evaluation is to look at the user experience (UX) of the inventory analyzer visualizations. UX is regarded as a key factor for the success of almost any product [51]. To achieve a comprehensive view of the UX of the inventory analyzer visualizations, the modular evaluation of key Components of User Experience (meCUE) questionnaire [52] was adopted. The mEQUE aims to measure key components of user experience in a comprehensive and unified way [51]. The meQUE questionnaire is based on the Components model of User Experience (CUE) by Thüring and Mahlke [53]. Due to the modular configuration of meCUE, the questionnaire can be easily adapted to specific research goals by simply choosing those modules which are required [51]. It was decided to adapt module I, perception of instrumental qualities, and module II perception of non-instrumental qualities. From those modules, the following items were adopted: Usefulness, Usability from module I and visual aesthetics from module II.

A self-administered questionnaire and semi-structured interviews will be used as research instruments. The questionnaire is designed based on the questionnaire items of the UTAUT and the meCUE questionnaire. The questionnaire and interviews will be discussed in detail in Chapter 9.

4

Phase 1: Empathise

The first stage of the design process entails gaining empathy for the stakeholders to gain insights into their needs, thoughts, emotions, and motivation. An effort is made to relate to the user and comprehend their situations, as well as why certain experiences are meaningful to them. Employees at AEMICS will be the eventual users of the product developed in this graduation project. The initial step at this stage is immersion at AEMICS by visiting the company on a regular basis, talking to personnel, and observing. After having been immersed, group sessions with stakeholders are conducted to better understand their thoughts and feelings. Based on the information acquired during the immersion and group sessions, a description of the stakeholders, an overview of pain points, and an outline of wishes are generated. The findings will be discussed in this chapter.

4.1 STAKEHOLDERS

The product that will be developed in this graduation project will eventually be integrated into the ERP system of AEMICS. As a result, the stakeholders of the product are AEMICS' employees. Each of these people uses the ERP system for a different reason, depending on their position within the organization. Figure 12 depicts an overview of the various stakeholders.

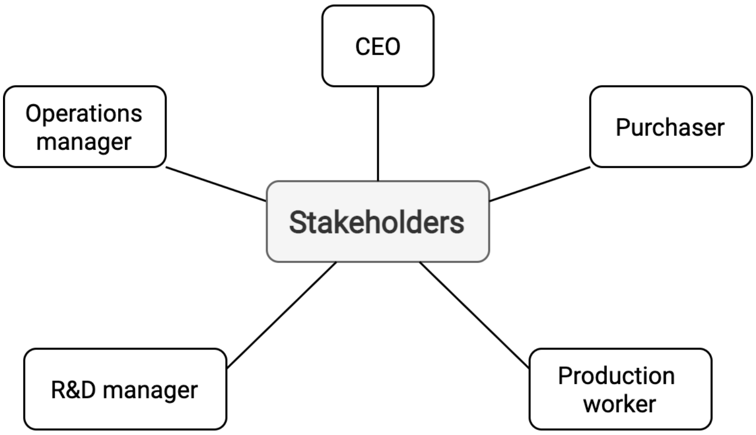

Figure 12. Overview of the stakeholders

Stakeholders who should be considered during the design process include the chief executive officer (CEO), executive assistant, purchasers, production workers, research and development (R&D) manager, and operations manager. The CEO is in charge of AEMICS' operating plan, which is essential to accomplishing the company's objectives. In addition to administrative work, the executive assistant is in charge of human resources at AEMICS. The procurement officer is responsible for evaluating suppliers, products, and services, as well as negotiating and ensuring that approved purchases are both cost-effective and of good quality. AEMICS' production team is made up of production workers, whose primary task is to install and attach electronic components within a device. This is accomplished by attaching elements to a circuit board with machines, hand-soldering components, or using other hand tools to connect and adjust individual electronic components. They are also responsible for executing quality assurance tests, inspecting components, and correcting component defects. The R&D manager oversees R&D processes within AEMICS, which include applied research, product development, and prototyping. Finally, the operations manager is in charge of overseeing all of the production team's activities in order to ensure efficient manufacturing and engineering at reasonable costs.

4.2 PAIN POINTS

In this graduation project, group sessions, as described in Section 3.2, were organised with the aim of discovering what the pain points related to inventory are. In this context, a pain point is defined as a specific problem that AEMICS personnel are currently experiencing. There were two group sessions with three participants each. The CEO, the procurement officer, and the R&D manager were part of the initial group. The second group was made up of three electronic assembly operators from the production team. During the group sessions, the brain dumping technique was applied. The participants were asked to write down any problems that came to mind when they considered AEMICS' current inventory management. Based on the input received during the group sessions, the collected pain points were documented. A complete overview of the pain points that were written down can be found in Appendix F. The outcomes of the effort/importance matrix are displayed in Appendix G. The pain points are classified as ERP system, inventory, production, Kanban, procurement, dropout/load loss, or general. The following sections will go over the findings.

4.2.1 ERP system

AEMICS uses its enterprise resource planning (ERP) system for collecting, storing, managing, and interpreting data from a variety of their business activities. The ERP system displays the location of the carriers. However, one issue mentioned during the group meetings was that not all the carriers' locations are known. Moreover, component parameters (such as predicted dropout and load loss) are sometimes missing. Another common issue was that there is a mismatch between reality and the information displayed in ERP. For example, the quantity displayed in ERP may not always correspond to the current inventory of a component. Furthermore, a pain point raised was that VAT is not excluded in some of the prices shown in ERP.

As mentioned in Section 2.2.5, a stacked bar graph is displayed in ERP for each production process sheet to provide an overview of the progress. The stacked bar graph displays how many products completed the step, needed to complete the step, were discarded, or appeared to be incorrect. The quantity indicated in a production sheet step is not always correct, which is a problem. The main reason for this is that personnel periodically forget to write off components from a carrier.

Each component is assigned a manufacturing part number (MFPN), which is a unique identifier issued by manufacturers to identify individual components. One point raised was that the MFPN is not always correct. Furthermore, there is no way to correlate multiple MFPNs with a single component. This is inefficient because multiple components must be added rather than a single component with multiple MFPNs.

AEMICS will estimate the product costs, effort, and time after receiving a request for quotation, as described in Section 2.2.1. It was mentioned during the group session that there is frequently a significant mismatch between reality and the estimations made when the request for quotation was received. For example, an estimate is created of how much the components required to manufacture the product will cost. However, in practice, these costs are sometimes higher than expected. These expenses are determined by component prices from suppliers. It is also possible that the lead time for one of the required components is significantly longer than expected, or even worse, the component could not be ordered because it is out of stock at all suppliers. An estimation that is considerably different from reality may result in delayed delivery of the product to a client, or difficulties with the schedule of the production team. If there are more costs than expected there is less profit earned.

There is a lot of data related to the production of the components. One of them are the bill-of-materials (BOMs). A problem that has been raised is that the BOM can change between picking components from the inventory and putting them in the machine. Besides that, BOMs are not always correct because components that should have been included in the BOM are sometimes missing. In addition, the state of a component (for example, active, obsolete, or prototype) is not always correctly displayed in ERP.

4.2.2 Inventory

When a carrier is empty, the barcode should be scanned to reduce the component's inventory level in ERP. One complaint was that people occasionally forget to scan the barcode of an empty carrier. It was also stated that mistakes occur when a supplied component is placed in stock. One of the mistakes identified was putting improper stickers on a component. Furthermore, the shelf-life of components (for example, pasta and flux) is not considered. In addition, there is currently no stocktaking taking place.

Another issue that has been raised is the quantity of a component that should be kept in inventory. It was mentioned that there is too much inventory, much of which is underused. Components are occasionally ordered even when there is a substantial supply of that component in stock. On the other hand, it is occasionally the case that there are insufficient components to make a product. During the sessions, the phrase "miss out" was frequently used. A product, for example, could not be manufactured if a component was not available. Or a component cannot be ordered because the supplier does not have it in stock.

Another concern raised was the difficulty in determining whether it is permissible to reject a carrier with a limited number of components. This is dependent on the value of the components on the carrier, which is difficult to predict.

4.2.3 Kanban

AEMICS uses the term Kanban to refer to inventory items that are frequently used. Each Kanban component has its own minimum threshold, and when a component's inventory level falls below it, it should be ordered to replenish the stock. One issue with Kanban items is that it is not clear which components are advantageous to include as Kanban items. It is unclear when something transitions from project-based to a Kanban item. There is also no way to decide when a component should no longer be a Kanban item.

Another concern has been made about the minimum threshold for Kanban items. It was stated that Kanban quantities are not always appropriate and that there is no method for determining Kanban quantities. Finally, the actions required to order Kanban products are time-consuming and inefficient. The purchaser must manually review the current stock in the ERP system to determine whether a component needs to be reordered in order to replenish the Kanban inventory level to the minimum threshold.

4.2.4 Dropout and loadloss

There are several causes of losses that occur throughout the manufacturing process. Dropout and loadloss are two major types of losses. One issue raised was a discrepancy between the predicted dropout and loadloss values and the actual dropout and loadloss values. It was mentioned that the anticipated loss levels, particularly for prototypes, do not correspond to the actual loss values. The actual dropout and loadloss of components are currently kept in the database. One concern raised was that there is currently not anticipated on actual dropout and loadloss values of a component. Another issue raised was the need to load the roles on the feeders several times when using feeders between projects, resulting in multiple losses.

The anticipated dropout and loadloss values are linked to a component. However, when the expected dropout and loadloss are determined, the packing type of that component is not taken into account. This is a problem since the packing type influences the loss of a component in the manufacturing process.

5

Phase 2: Ideate

Ideation is the process of generating many diverse ideas to examine a variety of possible solutions. Co-creation sessions with stakeholders are held during the ideation phase to gather knowledge and ideas from a wide range of people. This chapter will go over the ideas that were gathered during the co-creation sessions.

5.1 RESULTS OF CO-CREATION SESSION 1

Co-creation sessions were employed as part of the Ideation phase, as outlined in Section 3.3. The CEO, the procurement manager, and the R&D manager participated in the first co-creation session. As a starting point for ideation, four categories were used: purchasing components for production process sheets takes too much time, purchasing Kanban components takes too much time, daily update, and inventory mismatch. The results of this co-creation session can be found in Appendix H. This section will elaborate on the ideas developed for each category.

5.1.1 Purchasing components for production process sheets takes too much time

An idea is that when an order is placed with a distributor, let them know what the expected delivery time is. Purchasing could be optimized by comparing distributor inventory levels and prices. Another idea was to automatically check the current inventory before an order is placed. Moreover, orders may be placed using an API. Order confirmations could be automatically handled. It was also suggested that after optimizing the purchasing list, it should be exported to purchasing lists for each distributor so that an order with the distributor may be placed all at once. Finally, an idea was to have a procurement dashboard with expected mutations. As a result, it is possible to anticipate those mutations sooner.

5.1.2 Purchasing Kanban components takes too much time

To address the issue that purchasing Kanban items takes too long, it should be automated. One proposal was that a Kanban purchasing list could be generated automatically each week. Similarly, an employee mentioned creating a procurement list based on current inventory levels, expected inventory use, and distributor delivery time.

5.1.3 Daily update

There were four ideas in the category *Daily update*. One of the ideas was to update open purchasing lines on a daily basis. Other suggestions in this category were about the supplier information presented in ERP. As indicated in Section 2.2.5, ERP allows you to view the inventory level and pricing of a component at several suppliers. This information will be manually updated once a component's refresh button is hit. The information is not updated automatically since there is a so-called "rate limit" that determines the number of requests that may be made in a given time period. As a result, the information provided for a component, such as inventory levels at suppliers and pricing, is not always up to date.

The first idea was to check on a daily basis to see if a supplier's rate limit was being exceeded. If the limit is not reached, request the supplier's inventory level and pricing for each component. Another suggestion was that instead of manually updating the supplier information for each component, it might be collected and updated automatically. Each supplier's rate limit should be taken into consideration automatically.

Furthermore, the importance of updating the supplier's information for a component might be evaluated. If there are significant price discrepancies across components, it is critical to have up-to-date information. When ordering large quantities of a component, the difference in pricing becomes much more important.

5.1.4 Inventory mismatch

One of the problems is a mismatch between the values displayed in ERP and the actual numbers. A possible solution mentioned in the co-creation session was to use triggers on illogical mutations. Another idea was to develop a consumption and forecast graph for each component and use deviations between those graphs as a trigger. Furthermore, someone suggested that the inventory forecast could be compared to the actual inventory levels.

As displayed in Figure 7, multiple steps are associated with a production sheet. It was suggested that the step of a production sheet in which a component is used should be documented. In ERP, an employee can complete a step of a production sheet. When a step is completed, it is marked as complete in ERP. One suggestion was to automatically write off the consumed component quantity when a step is set to complete. Another suggestion was to compute the monthly purchase value of each component. Furthermore, the daily inventory mutations could be displayed in terms of the price of each item that is used.

5.2 RESULTS OF CO-CREATION SESSION II

The second co-creation session was held with four electronic assembly operators of the production team. The categories utilized as a starting point for ideation are based on the group session that was held during the Empathise phase. The four categories are: Kanban, Triggers, BOM, and Other. The results of this co-creation session can be found in Appendix I. This section will go over the ideas that were developed for each category in further detail.

5.2.1 Kanban

During the co-creation session, one of the ideas considered was to automatically purchase Kanban components once a week. Furthermore, it was suggested that procurement can be improved by identifying which components should be included as Kanban items.

5.2.2 Triggers

Different parameters of a component, such as dropout and loadloss, are shown in the ERP system. One of the existing issues is that some components miss parameters. One proposed solution is to automatically verify if a component has all of its parameters and, if not, to generate a trigger. Another concept was to display component loss in the ERP system and offer a trigger to the production team if the loss was significant. A related idea was to determine where the bottlenecks are related to machine loss.

5.2.3 BOM

The bill of materials (BOM), which is a list of the components required to manufacture the product, does alter from time to time. One of the ideas was to send a trigger notification when the BOM changed. Another idea was to have the production team check the BOMs before placing orders. Furthermore, it was suggested that the BOM should be modified to include all elements (incl. packaging).

5.2.4 Other

One proposal for enhancing procurement was to inspect current stock more regularly during the purchasing process. Alternatively, before placing the order, the bin might be examined to see whether there is any inventory available. It was also suggested that the production team should be more involved in work preparations. Furthermore, one of the suggestions was to create a general inventory, which would result in a better overview, fewer containers, and fewer locations within the inventory. It was also recommended that the expiration date should be included in a component's parameters. Furthermore, it was suggested that the procurement should take drop out and load loss into account, even with prototypes. Another idea was to keep track of SMD hand assembly in hours. Furthermore, the remaining value (price) of a carrier could be displayed. When a project is completed, the bags holding a small number of components should be discarded.

6

Phase 3: Converge

The third stage is known as the convergence phase and it is where ideas are evaluated, compared, ranked, clustered, and dropped to put together a few great ideas to act on. The results of the convergent stage are presented in this chapter. The first section describes the findings of the 2x2 matrix, which was used to evaluate the potential and feasibility of concepts. The description of the concept to be developed in this graduation project will then be discussed.

6.1 MATRIX

A matrix was used to assess the feasibility and potential of ideas. Each sticky note with an idea on it was placed on the graph in a different location. At the end of the co-creation session, all participants evaluated the ideas collectively, as detailed in Section 3.4. Due to time constraints, the matrix was only used during the first co-creation session with the CEO, procurement manager, and R&D manager, and not during the second. Figure 13 depicts the finished matrix with the concepts. The ideas are grouped if they are related, as shown by the areas enclosed by a dotted border in Figure 13. Ideas were developed for different categories, as indicated by the colours in the figure. The four categories that were employed are as follows: purchasing components for production process sheets takes too much time, purchasing Kanban components takes too much time, daily update, and inventory mismatch. The previous chapter contains a description of the concepts.

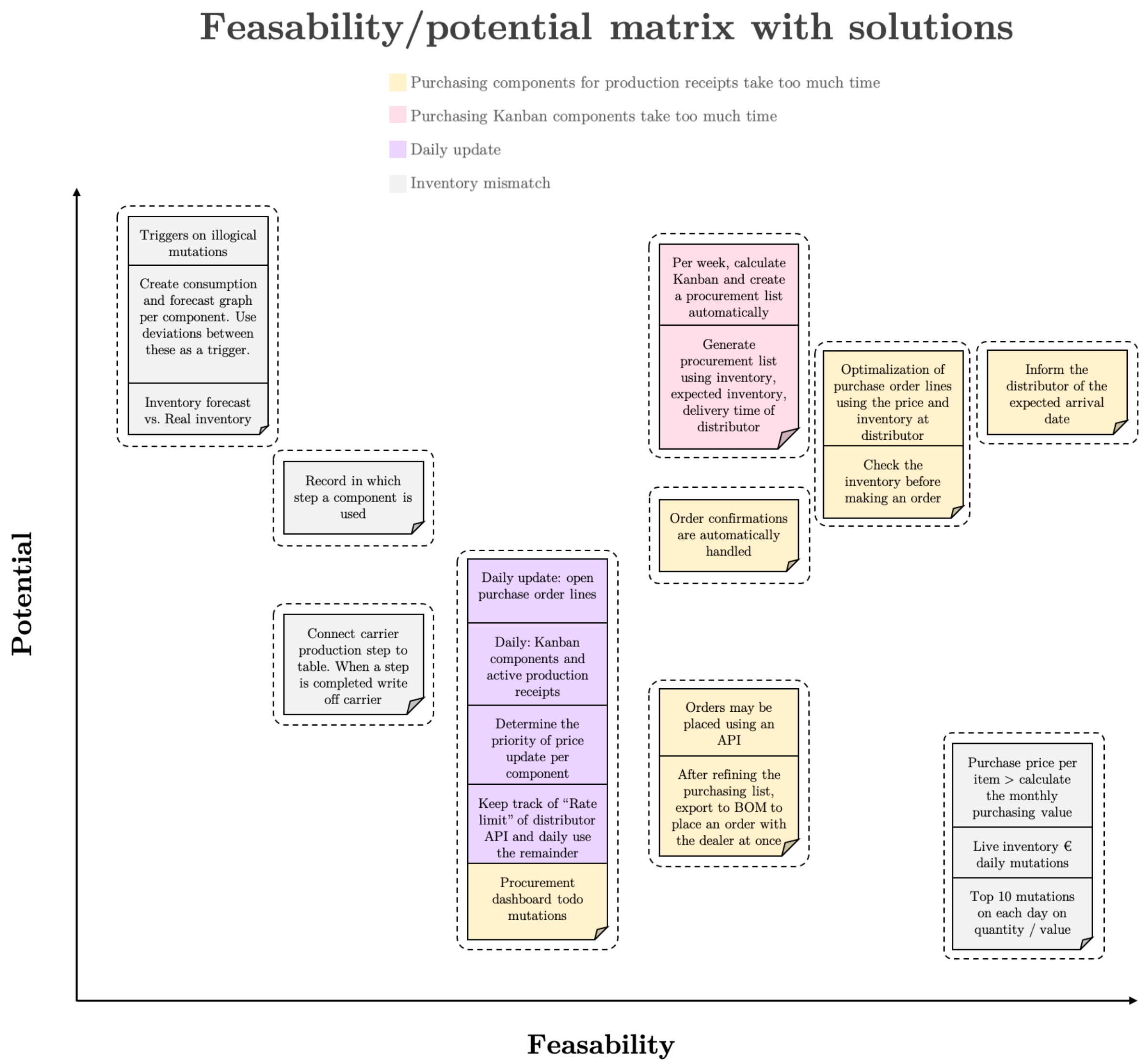

Figure 13. Feasibility/potential matrix

Since there is a limited amount of time to develop and implement the concept, it was decided in collaboration with the major stakeholders to focus this graduation project on just one of the ideas. The selected concept will be described in the next section.

6.2 CONCEPT

The selected concept is based on the group with ideas in the top left corner in Figure 13. The purpose of the concept called "Inventory analyzer" is to provide a consumption and forecast graph for each component. The concept will be explained in greater detail in the following section.

6.2.1 Description of the chosen concept

The inventory analyzer will have a variety of functions. The five key elements that will be implemented are depicted in Figure 14. Each feature will be discussed in further detail in Section 7.3.

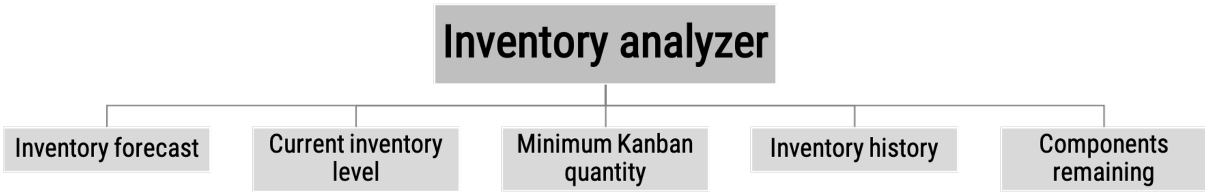

Figure 14. Overview of the inventory analyzer's main features

Inventory forecasting, which is a method for predicting inventory levels for a future period, will be one of the inventory analyzer's features. The forecast will be based on the components required for sprint-planned production sheets and the components that are expected to be delivered. Another feature of the inventory analyzer is that it should be able to return the current inventory level of each component and the minimum Kanban quantity. The minimum Kanban quantity refers to a component's threshold below which current stock should never fall. Only components labelled with "Kanban" have a minimum quantity. Returning the minimum Kanban quantity is beneficial since it may be interesting to see how much the inventory levels deviate from the minimal amount.

Moreover, the inventory analyzer will be able to return the historical inventory levels of a component. Finally, the inventory analyzer will supply the remaining components of a production process sheet. The production process sheet is a list of all steps taken in the process of manufacturing a specific product. The remaining components are the same as the BOM if the production process sheet has not yet been started. If the production process sheet is already in progress, some of the components may have been used and are no longer required. The remaining components are those needed to finish the production process sheet.

6.2.2 Motivation behind the concept

There are different reasons why this concept was chosen. It was agreed during the co-creation session that this concept has the most potential. In addition, the concept contributes to extracting greater value from the available data. Another reason for choosing this concept is the numerous benefits it will provide for AEMICS. The inventory analyzer has the potential to improve AEMICS workers' negotiations. The concept can supply employees with information that will assist them in making well-informed decisions. Economic benefits are expected from the concept since it can streamline the procurement process, speeding up the process and requiring less work and people.

Another potential advantage is enhanced accuracy because the purchasing staff can quickly extract insights from the inventory analyzer. Historical data assists in making efficient strategic decisions. The inventory analyzer will not only make data more accessible to staff, but it will also save time and make it easier to discover trends. The visualizations will be generated automatically and efficiently from the available data. Data visualizations have a standard layout, which makes them easier to comprehend. This will result in increased compliance. Finally, a competitive advantage might be achieved because procurement is more efficient. Figure 15 depicts an overview of the potential benefits of the inventory analyzer.

Figure 15. Overview of the potential benefits of the concept

6.3 REQUIREMENT ANALYSIS

6.3.1 Use cases

The use case diagram in Figure 16 depicts the various interactions that an actor may have with the inventory analyzer. A purchaser, a member of the production team, and an operational manager are the actors considered in the use case diagram. Viewing the expected changes in a component's inventory level is one of the use cases. Another use case is to check the remaining components required to finish a production process sheet. Moreover, a use case is to view the current inventory level of a component. Viewing the history of a component's inventory level is another use case. Finally, a use case is to determine the minimal Kanban quantity of a component.

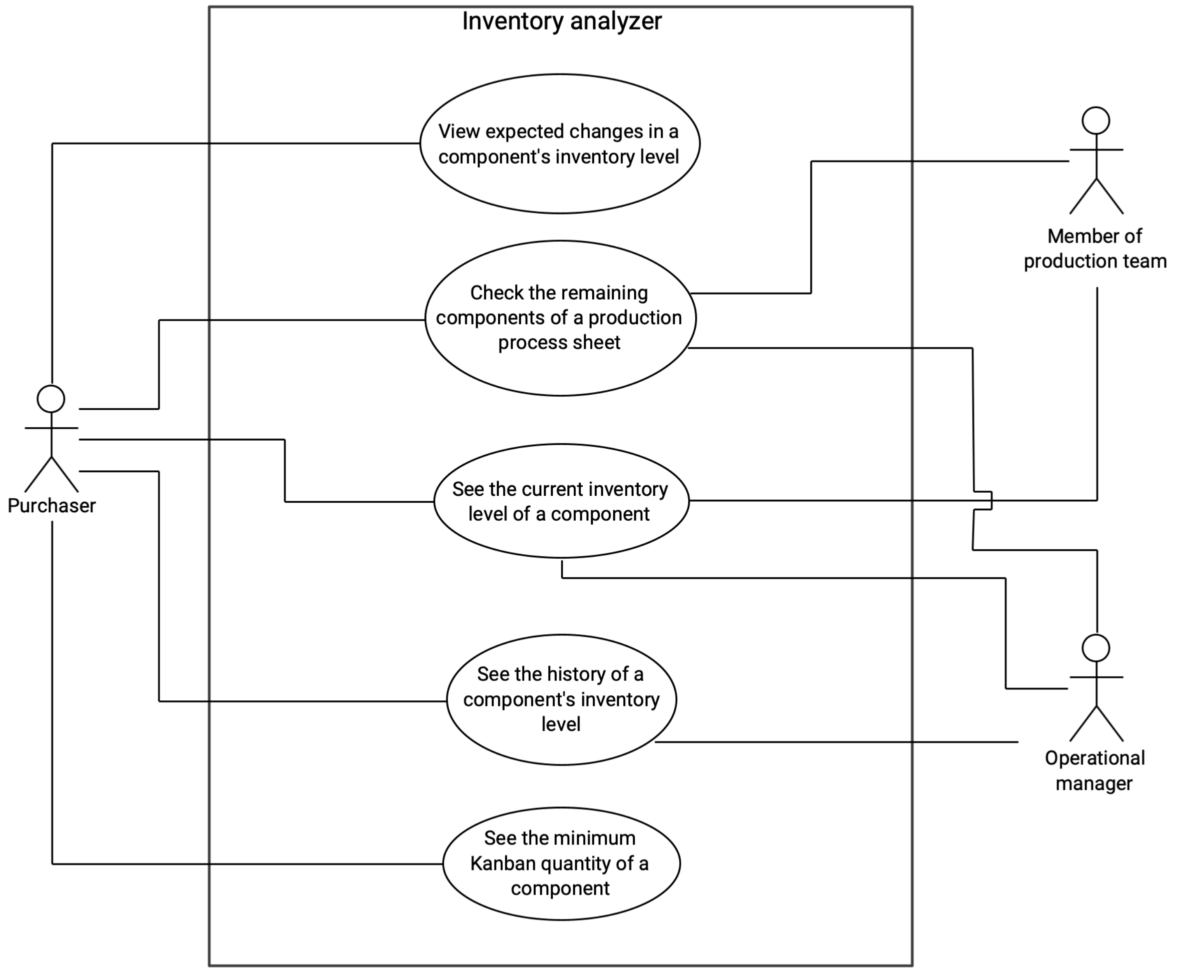

Figure 16. Use case diagram of the interaction with the inventory analyzer

6.3.2 User stories

This section presents the user stories which were written to describe the functionality of the inventory analyzer. The user stories describe features that will be valuable to a user. The following template will be used for the user stories "As a ⟨role⟩, I want ⟨goal⟩, [so that ⟨benefit⟩]" [48].

Inventory forecast

- As a purchaser, I want to be able to examine the expected changes in a component's inventory level in order to determine whether the inventory level of a Kanban component falls below the Kanban minimum quantity.
- As a purchaser, I want to be able to see the expected changes in a component's inventory level in order to determine whether the inventory level becomes negative, indicating that I should order the component in order to have enough for production.

Inventory history

- As a purchaser, I want to be able to see the history of a component's inventory level to determine whether the component's inventory level is on average around the Kanban minimum quantity.
- As a purchaser, I want to be able to view the history of a component's inventory level to determine how much the component has been used in the past.
- As an operational manager, I want to be able to view the history of a component's inventory level in order to determine whether the inventory level was negative, indicating that something went wrong.

Remaining components

- As a member of the production team, I want to be able to examine the remaining components of a production process sheet so that I can immediately assess whether there are enough components on hand to complete the production process sheet.

- As a purchaser, I want to be able to review the remaining components of a production process sheet to determine whether components need to be ordered to ensure that the steps in the production process sheet can be completed.
- As an operational manager, I want to be able to see the remaining components of a production process sheet so that I can determine whether to make modifications to the planning. If there are not enough components to finish a specific production process sheet, but there are enough to finish another, the order of the planning could be adjusted.

Current inventory level + minimum Kanban quantity

- As a member of the production team, I want to be able to see the current inventory level of a component so that I can determine whether there are enough components on hand to manufacture a product.
- As a purchaser, I want to be able to see the current inventory level of a component as well as the minimum Kanban quantity so that I can determine the difference. If the current inventory level is less than the minimum Kanban quantity, the component should be ordered.
- As an operational manager, I want to be able to view the current inventory level of a component to determine whether the inventory level was negative, indicating that there is a mismatch between reality and the system.

6.3.3 Functional requirements

The requirements serve as the foundation for the development of the inventory analyzer. The goal of requirement specification in this graduation project is to create a minimal set of requirements that reflect the intended purpose and underlying vision of the inventory analyzer. Since there is a limited amount of time to develop the inventory analyzer, it is more convenient to start with a small number of essential functionalities. Table 1 shows the main functional requirements of the inventory analyzer.

Criteria
• The system should be able to provide the expected changes in a component's inventory level. • The system should be able to determine the remaining components of a production process sheet. • The system should be able to determine the current inventory level of a component. • The system should be able to return the history of a component's inventory level. • The system should be able to return the minimum Kanban quantity of a Kanban component.

Table 1. Overview of the functional requirements

The system can be designed based on the requirement analysis. The next chapter will go over the system design in depth.

7

System design

The concept for this graduation project emerged during the convergence phase. The purpose of this chapter is to present the design of a system that satisfies the requirements as specified in the previous phase. This system design will convert the requirements into a functional system. The first section will present the system architecture, which is a formal description and representation of a system. Following that, the tools that will be used will be described. Finally, there will be a description given of how the features may be implemented.

7.1 ARCHITECTURE

As previously stated, the current system of AEMICS is separated into microservices that operate independently and communicate with one another. Therefore, the inventory analyzer will be implemented in the system as a microservice. Microservices, also known as microservice architecture, is an architectural approach that structures an application as a series of highly maintainable and tested services. Microservices are deployed independently, and therefore, every update or feature delivery may be done without affecting the application. More importantly, it is possible to track the performance of each service and easily isolate problems from other services that are operating. Each microservice has its own database and maintains its own piece of data, rather than a single massive database holding all information.

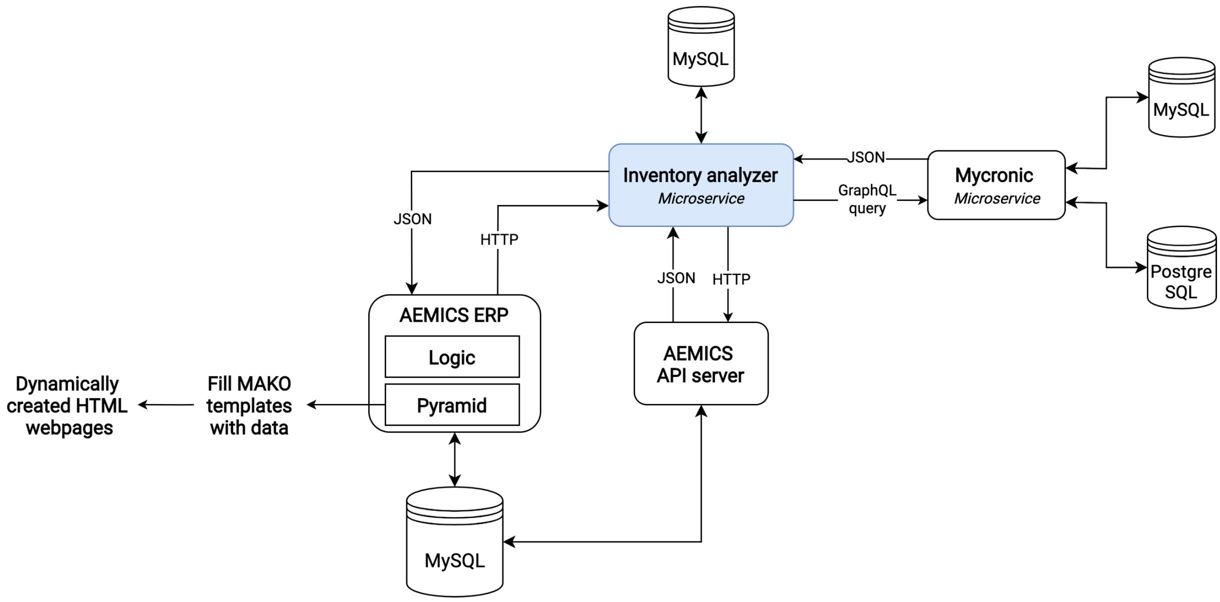

Figure 17. Architecture of the concept

Figure 17 depicts the system architecture of the inventory analyzer. As indicated in the figure, the inventory analyzer will be constructed as a microservice with its own MySQL database. The inventory analyzer may retrieve data from AEMICS' main database by sending GET requests to the core API. Moreover, the inventory analyzer will request data from the Mycronic microservice. Mycronic refers to the name of AEMICS' pick-and-place machine, which is used to place electrical components onto printed circuit boards. The Mycronic microservice is responsible for caching and exchanging carrier-related information. GraphQL queries will be used to retrieve data from the Mycronic microservice. GraphQL will be explained in Section 7.2.2.

To allow other services to communicate with the microservice, an application programming interface (API) will be added to the inventory analyzer. This ensures that an external service can provide a simple command, and the inventory analyzer will respond with the requested data. The front end of the inventory analyzer will not be a separate application; rather, it will be integrated into AEMICS' ERP system. The ERP system will send requests to the API of the inventory analyzer. The inventory analyzer will provide data from its MySQL database, and the ERP system will display visualizations depending on the returned data. To create HTML files dynamically, the ERP system employs a combination of the Pyramid framework and Mako templates. These tools will be covered in Section 7.2.4.

7.2 TOOLS

7.2.1 Microservice

The Flask framework will be used to build the microservice. Flask is a micro web framework used to build web applications. Flask is classified as a microframework because it does not require any special tools or libraries [54]. Extensions can be used to add extra functionality to a Flask application. The benefit of using Flask is that it is meant to make getting started quick and straightforward while yet having the potential to scale up to complex applications [55].

The inventory analyzer will identify the current stock, minimum Kanban amount, inventory level history, and predicted inventory level mutations. An API will be built, ensuring that an external service may issue a simple command and the inventory analyzer will respond with the requested data. The Flask-RESTful extension will be used to build a REST API. Flask-RESTful provides a *Resource* base class, which will be used to generate various resources for the inventory analyzer API. The resources are linked to data sets that may be accessed via endpoints [56]. The following code can be used to build one resource. The endpoints provide how to access the resource.

```
from flask import Flask
from flask_restful import Api, Resource

app = Flask(__name__)
api = Api(app)

class ExampleAPI(Resource):
    def get(self, id):
        pass

api.add_resource(ExampleAPI, '<end_point>')
```

Parameters are options that may be added to the endpoint to influence the response. After an endpoint, the parameters should be supplied in the following form: `?param=value`. The global object *request* from the Flask package will be utilized to obtain the value of a parameter.

The open-source platform Docker will be used to package and run the Flask application in an isolated environment called a container. Containers are lightweight and contain everything needed to run the application, allowing the application to run quickly and consistently independent of the computing environment in which it is operating [57]. A Docker image is a file that is used to execute code in the container [58]. A Dockerfile is a text file that contains all the commands needed to build an image [59].

A MySQL database will be used to store the inventory analyzer data. MySQL is a relational database management system that organizes data into one or more data tables with data types that may be related to one another [60]. Moreover, the Flask-SQLAlchemy extension will be utilized to make use of the SQLAlchemy package, which is an Object Relational Mapper (ORM). ORM is a tool that can be used to convert high-level processes into database instructions. Flask-SQLAlchemy enables database management using high-level entities such as classes, objects, and methods rather than tables and SQL.

7.2.2 Communication with Mycronic microservice

The inventory analyzer will request data from the Mycronic microservice in order to obtain the carrier-related information required to establish the history of inventory levels as well as the current stock. Since the Mycronic microservice is a GraphQL API, the inventory analyzer should send GraphQL queries to request data. A GraphQL API allows clients to define the structure of the data needed, and the same structure of the data is returned from the server [61]. The benefit is that it prevents the server from returning unnecessarily huge amounts of data.

7.2.3 Communcation with core API

AEMICS has implemented a REST API architectural style as an application program interface (API) that accesses and uses data through HTTP requests. The API server is referred to as the core API since it is linked to AEMICS's core database. The aemics_api package makes it simple to send requests to the API. Table 2 depicts an overview of the requests that will be sent to the core API.

`response = api.connection.get_request("/sprints", params={'state': ['FUTURE', 'ACTIVE'], 'team': 'Series'})`	

`response = api.connection.get_request("/sprints", params={'state': ['FUTURE', 'ACTIVE'], 'team': 'Series'})`
Retrieve sprint information, only sprints with the status 'FUTURE' or 'ACTIVE,' and from the team 'Series'.
`ticket_data = api.connection.get_request("/tickets", params={'state': ['Pending', 'In progress']})`
Retrieve information from production process sheets with the status 'Pending' or 'In Progress.'
`remaining_components = api.connection.get_request(f"/remaining_assembly/{ticket['id']}")`
Retrieve the remaining components needed to complete the production process sheet. The ID of the production process sheet is given as a parameter of the request.
`purchase_lines = api.connection.get_request("/purchaselines",params={"ordered": True, "delivered": False})`
Retrieve information about purchase lines that have been ordered but have not yet been delivered.
`components =  api.connection.get_request('/components', {'min': index, 'max': index + query_length})`
Retrieve information about the components. Since the number of components from which the information may be collected in a single request is limited, several requests will be utilized through the min and max parameters.

Table 2. Requests that will be sent to the core API

7.2.4 Front-end

The front-end of the inventory analyzer will be implemented in the ERP system of AEMICS. The ERP system uses *Pyramid*, which is a Python-based web application framework. Pyramid is intended to make it simple to create web applications in Python. To dynamically generate web pages, Pyramid will be used in combination with Mako templates. Mako is a template library that allows content such as HTML to be integrated with Python. Mako allows the developer to write HTML directly and embed Python code when necessary. The JavaScript-based library *Chart.js* will be used to visualize the data received from the inventory analyzer. *Chart.js* supports eight different chart types: bar, line, area, pie (doughnut), bubble, radar, polar, and scatter.

7.3 IMPLEMENTATION OF FEATURES

7.3.1 Current inventory level

One of the features of the inventory analyzer is that it should be able to return the current inventory level of each component. As discussed in Chapter 2, most components that are purchased from a retailer come in tape and reel format, which means that the majority of components are stored on carriers. To determine the current quantity of a component in the inventory of AEMICS, the quantity of that component on each carrier it is on should be summed up together.

7.3.2 Minimum Kanban quantity

The minimum Kanban quantity refers to a component's threshold below which current stock should never fall. Only components labelled with "Kanban" have a minimum quantity. Since the minimum Kanban quantity is stored in a database, the inventory analyzer can retrieve it by conducting an API request. It would be useful for the inventory analyzer to include the minimum Kanban quantity in the visualizations of the inventory history and forecast in order to quickly observe how far the inventory levels deviate from the minimum amount.

7.3.3 Inventory forecast

Inventory forecasting, which is a method for predicting inventory levels for a future period, will be one of the inventory analyzer's features. The inventory analyzer monitors expected changes in a component's inventory level. Various factors can contribute to a change in a component's inventory level, as indicated in Figure 18. Each factor will be discussed in further depth in this section.

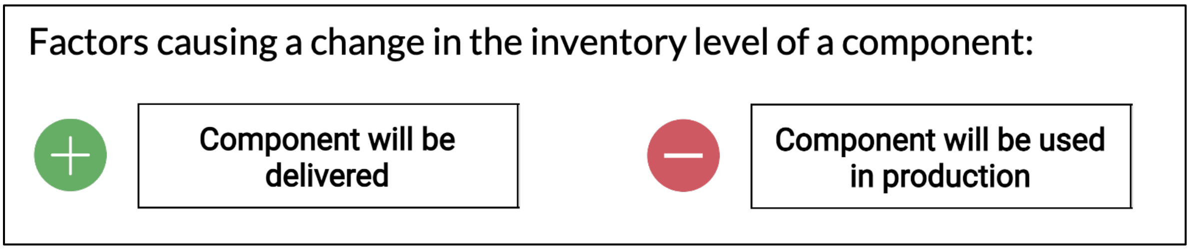

Figure 18. Factors that induce a change in a component's inventory level

As previously stated, AEMICS' production team works in sprints, with each sprint having its own set of production process sheets. The production process sheet consists of a list of all steps taken in the process to manufacture a particular product. A bill-of-materials (BOM) is related to the production process sheet, which comprises the components required to complete the steps in the production process sheet. The information from a sprint is stored in several tables in the database, as illustrated in Figure 19. The information related to the production process sheets is stored in the *'tickets'* table.

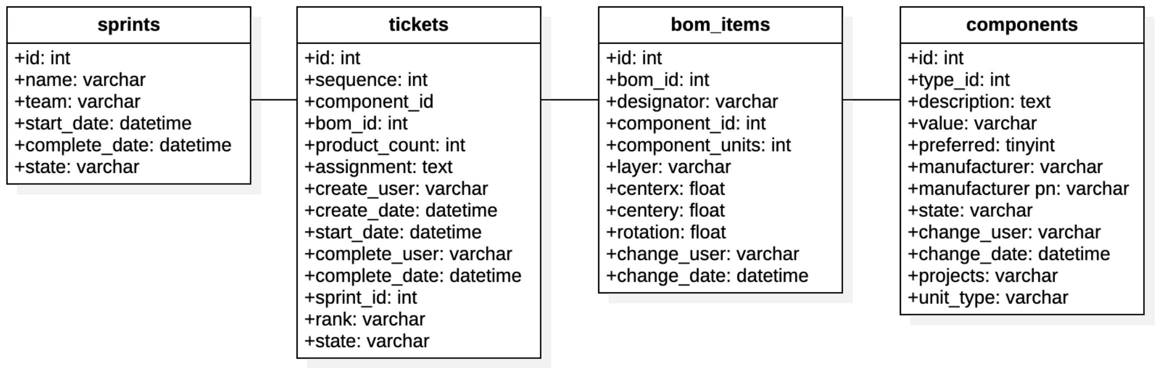

Figure 19. UML Class diagram of tables related to inventory forecasting

Sprint information is also provided in ERP, as shown in the screenshots in Figure 20. The left screenshot displays a list of sprints labelled closed, active, or future. Each sprint has a start date. The sprint planning is opened by pressing on the row of a sprint. After pressing the currently ongoing sprint, the sprint planning for that sprint is opened, as seen in the second snapshot in the figure. The sprint planning consists of a list of production process sheets that will be completed during this sprint. Each production process sheet has a unique ID, and by clicking on it, more information about the production process sheet is displayed. For instance, after clicking on the production sheet with ID ‘62004275', the information shown in the third screenshot is displayed. This information comprises a BOM ID that is linked to the production sheet. The BOM with ID '20100687' is related to the production process sheet with ID '62004275,' as indicated in the figure. The list of components on the BOM can be accessed by clicking on the BOM ID. After clicking on the BOM ID '20100687,' the list of components depicted in the figure's right screenshot becomes visible.

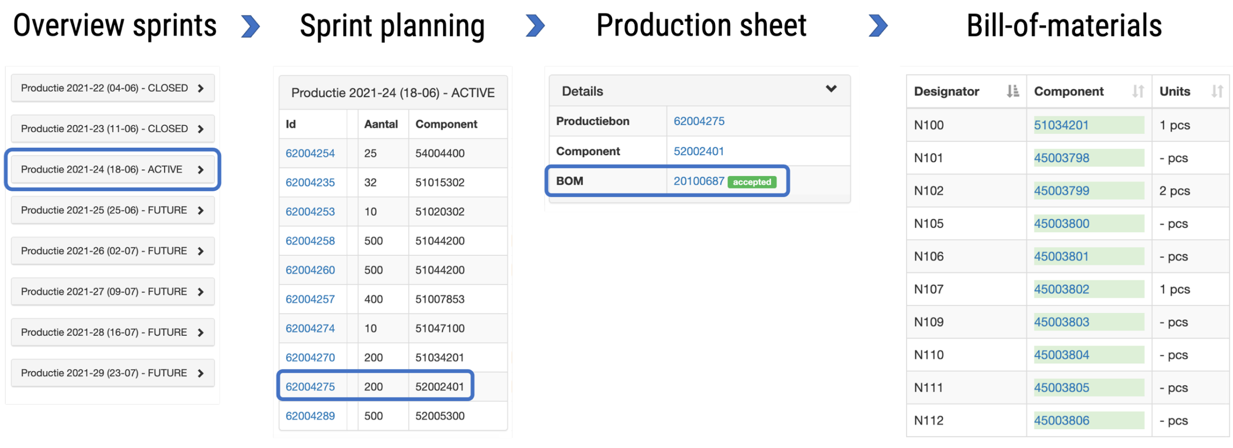

Figure 20. Screenshots of different parts in the ERP system

The consumption of components is determined utilizing the information available in the active sprint and future sprint planning. When a component is predicted to be used in a production process sheet, its inventory level decreases. There will be a distinction between production process sheets for the currently active sprint and production process sheets for future sprints. If the production process sheet is scheduled for a future sprint, it has not yet been started, and therefore the required component quantities can be found in the BOM. The predicted consumption for future sprints is all the components on the BOMs of production sheets that are planned for a future sprint.

If a production process sheet is part of the current sprint, it is possible that it is already in progress. As a result, some of the components may have already been used and are no longer required. Therefore, it is not possible to just extract the whole BOMs of all production sheets that are planned. A method should be used to retrieve the remaining components required to complete the production sheet. This method will be explained in Section 7.3.5.

In addition to component consumption, the estimate should include orders that will be delivered in the future. The data stored for each purchase item includes the ID of the delivered component, the number of how many are ordered, and the expected date of delivery. This information can be used to forecast inventory.

7.3.4 Inventory history

The majority of components are stored on carriers. When a carrier is loaded onto the P&P machine, the machine checks to see if the quantity of the carrier has changed. If the quantity has changed, the change is recorded in the machine's database. It is also possible that components from a carrier will be employed during hand assembling. The employee uses the ERP system to manually write off the quantity that was used from the carrier. Changes in the amount on the carriers are recorded, and these changes are used to determine the historical inventory levels of each component. As mentioned in Section 7.3.1, the current quantity of a component can be determined. To obtain the initial history quantity point of a component, the most recent carrier mutation is subtracted from the current quantity. The second carrier mutation is then subtracted from the quantity of the first history point to determine the second history point, and so forth. Appendix J depicts a flowchart of the determination of a component's inventory history. A simplified example is shown in Figure 21.

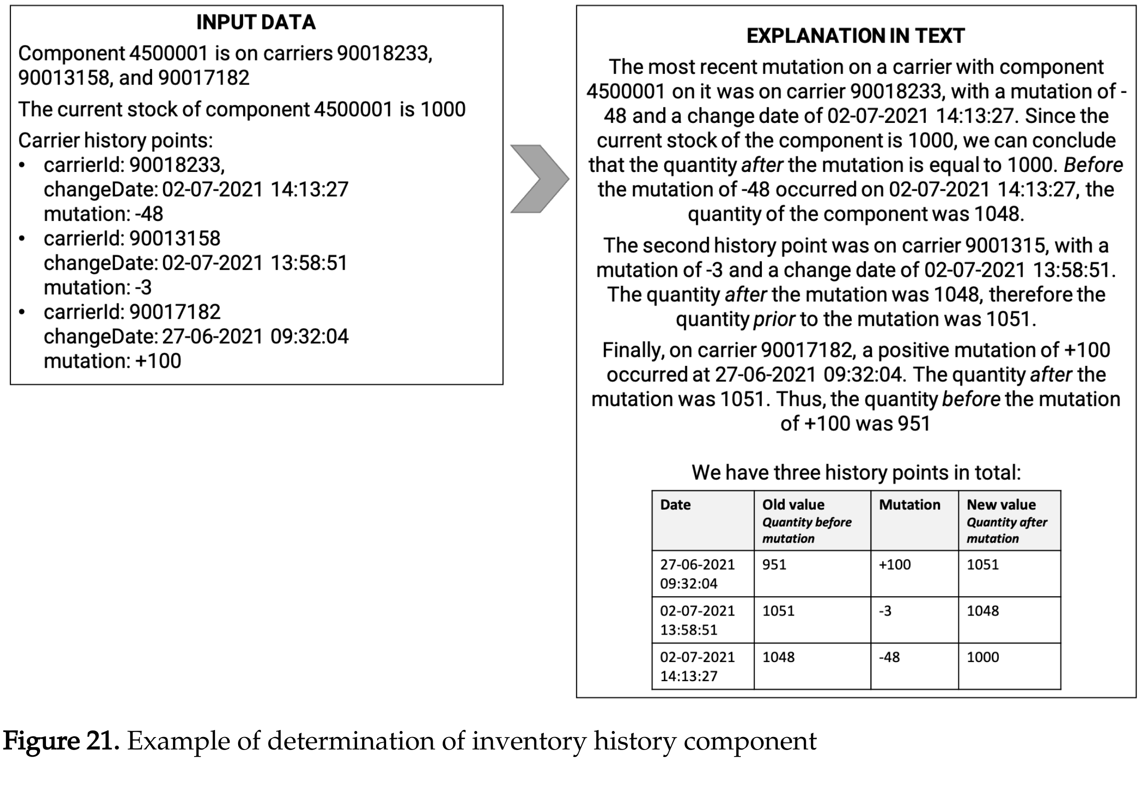

Figure 21. Example of determination of inventory history component

Since we start with the current stock value of a component and then calculate back to the oldest history point, we should go through the carrier history point lists from most recent to oldest. Each history point when a component quantity changed will be saved separately. It should be checked each time whether the current value should be used or whether there is already a history point for that component. If there is already a history point, we must choose the oldest one because it is the closest to the carrier history point. As a result, we must traverse the list of component history points from oldest to newest. The following is a simplified pseudocode:

```
for i ← 0 to history_point_list.length:
   comp_id ← history_point_list[i].get("componentId")
   carrier_id ← history_point_list[i].get("carrierId")
   history_point_date ← history_point_list[i].get("changeDate")
   mutation ← history_point_list[i].get("mutation")

   for j←running_stock.length to 0:
      comp_id_stock_point ← running_stock[j].get("comp_id")
      if comp_id == comp_id_stock_point:
         quantity_after_mutation ← running_stock[n].get("quantity")
         component_in_running_stock ← True

      if component_in_running_stock == False:
         quantity_after_mutation ← get_current_stock()
      quantity_before_mutation ← (quantity_after_mutation - mutation)
      stock_point_dict ←  {"comp_id":comp_id, "change_date":history_point_date,
      "quantity": quantity_before_mutation, "related_carrier": carrier_id }

      running_stock.append(stock_point_dict)
```

7.3.5 Remaining components

One of the inventory analyzer's features is that it may supply the remaining components of a production process sheet. The production process sheet consists of a list of all steps taken in the process to manufacture a particular product. If the production process sheet has not yet been started, the remaining components are the same as the BOM. If the production process sheet is already in progress, it is possible that some of the components have already been used and are no longer required. The remaining components are those that are still required to complete the production process sheet.

To identify the remaining components of a production process sheet, it is necessary to first determine which parts of a product have been completed and which have not. A product can be divided into three parts: top, bottom, and through-hole. Top and bottom relate to the layers of a printed circuit board (PCB), as seen in Figure 22. Through-hole components have pins that are designed to be mounted through a plated hole in the PCB.

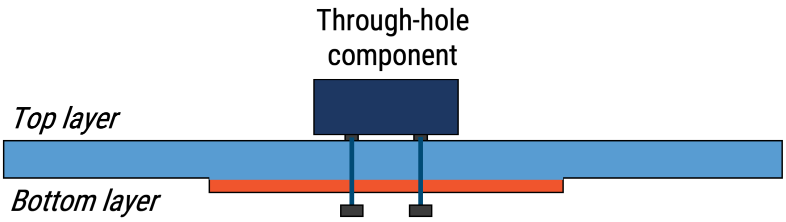

Figure 22. Schematic of a printed circuit board. Adapted from **[62]**

The following section will explain how it is determined which part of a product is completed. In a production process sheet, the same product is frequently manufactured many times. In other words, several instances of the product will be produced. Each instance will be assigned a unique identifier and recorded in the database. The class diagram in Figure 23 shows tables that are related to determining the remaining components of a production process sheet.

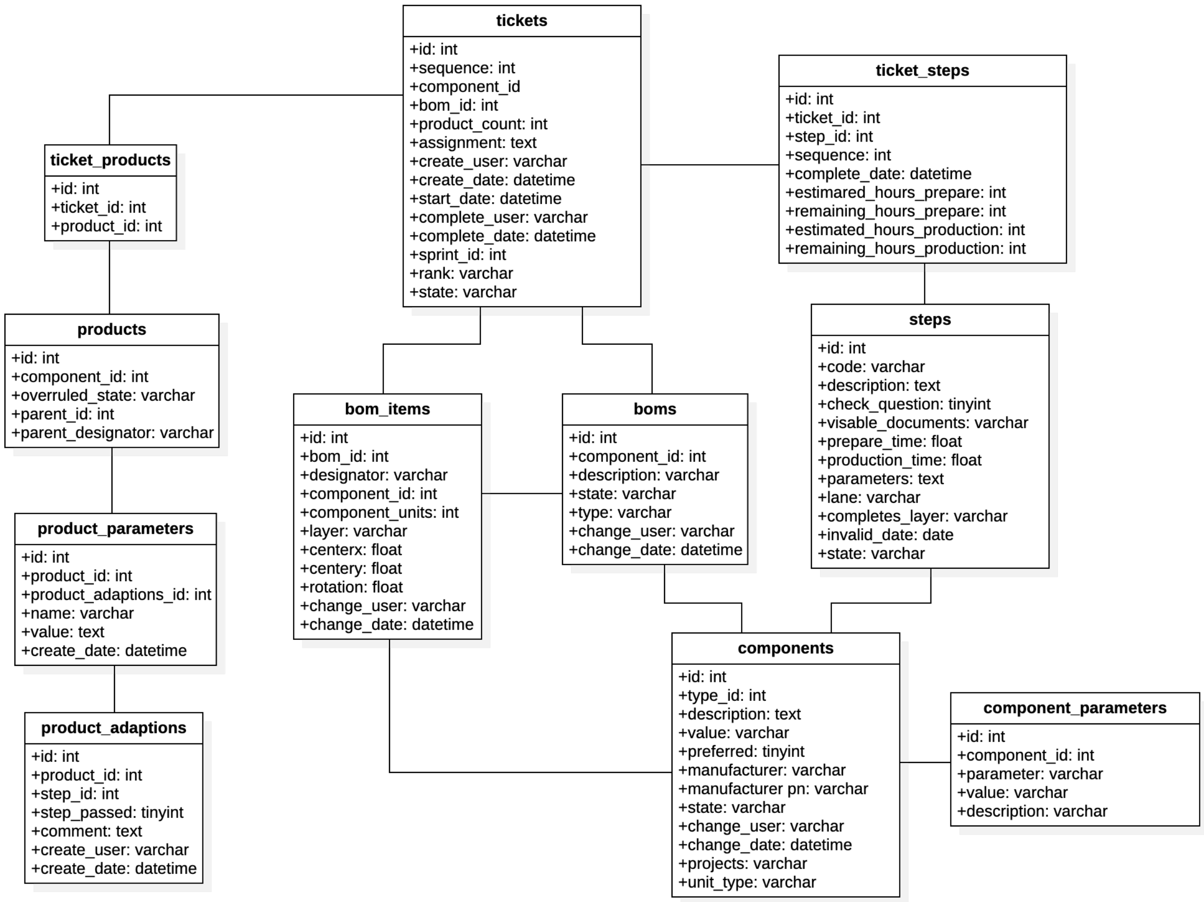

Figure 23. UML Class diagram of a part of AEMICS' database

A production process sheet, also known as a ticket, is saved in the table *tickets*. Each instance of a product that will be manufactured is saved in the table *ticket_products* with its own *product_id*. Each instance is linked to the table *product_parameters*. Each row in the *product_parameters* table has the value *product_adaptions_id*, which corresponds to an *id* in the *product_adaptions* table. The fields *step_id*, *step_passed*, *product_id* can be found in the *product_adaptions* table. The value of the field step_passed is either 1 or NULL. If the value is 1, then the step is completed. Based on the fields *step_id*, *step_passed*, *product_id*, it is possible to determine which of the steps has been completed for each instance.

After determining the completed steps for an instance, the completed layers will be determined. As explained in the previous section, the *step_id* of the completed steps can be retrieved. The field *completes_layer* in the table *steps* indicates which layer of the product is completed if the step with a specific *step_id* is executed. The possible values of *completes_layer* are TOP, BOTTOM, or NULL. By using the field *completes_layer* the layer associated with a completed step can be obtained. This is repeated for each completed step. As a result, the completed layers of a product are determined. The completed layers will be determined for each instance that will be manufactured. It is then possible to determine for each part (Top, Bottom, Through-Hole, Others) how many products still must complete that part.

Let us look at an example to understand what is meant. Assume that a production process sheet will create product X five times in total. Each product that will be manufactured has its unique ID: X1, X2, X3, X4, and X5. It is identified which of the products has already finished a part (top, bottom, and through-hole). It appears that X1, X2, X3 have already completed all parts. For X4 only the top layer has been completed. The manufacturing of product X5 has not started yet. Based on this information, it is possible to determine for each part (Top, Bottom, Through-Hole, Others) how many products still must complete that part. There is one instance (X5) where the top layer must still be completed. The bottom layer must still be completed in two instances (X4 and X5). Finally, there are two instances where all through-hole components have not been placed.

The preceding section explained how to determine for each part (Top, Bottom, Through-Hole, Others) how many products still must complete that part. Based on this information. This section describes how to proceed to get the remaining components of a production process sheet. The remaining components can be determined using the BOM, which is linked to the production process sheet. The BOM is a list of the components needed to finish the steps in the production process sheet. As previously stated, the following parts are distinguished: top, bottom, through-hole, and others. To identify the remaining components of a production process sheet, it should be established on which part the BOM item will be placed. The following paragraph describes the process for determining which part is linked to a BOM item.

The items of a BOM are stored in the table *bom_items*. The following steps are needed to check whether a BOM item is linked to *through-hole*. First, retrieve the *component_id* of the BOM item. Then look up this *component_id* in the table *component_parameters*. If there is a row where the field *parameter* is equal to 'TROUGH_HOLE_PINS' and the value is greater than 0, then the BOM item is linked to 'through-hole'. If the BOM item is not a through-hole component, then the field *layer* in the table *bom_items* can be used to determine the part associated with the BOM item. The value of *layer* is Top, Bottom, or Null. If the value is Null, then the BOM item is linked to the part 'Others'.

This paragraph provides the steps required to determine the remaining components of a production process sheet. To begin, the quantity of the BOM item must be retrieved. This is the quantity of the BOM item required to manufacture a single product. The BOM item is associated with one of the following parts: top, bottom, through-hole, or others. It is determined which part is linked to the BOM item. The number of products that still must complete that part is next calculated. The quantity of the BOM item (for a single product) is multiplied by the number of products that remain to finish the part of the BOM item. This approach is repeated for each item on the BOM to construct the remaining components for the production process sheet.

The steps described in the preceding paragraph yield a list of remaining components. This is the number of components required in the 'best case.' In other words, if there is no loss during the production process. The 'worst case will also be established by taking the drop out and load-loss into account. Both the worst- and best-case scenarios will be returned. Appendix K shows a flowchart of all steps described in this section to determine the remaining components.

To sum up, a production process sheet is associated with one or multiple instances of a product that will be manufactured. For each instance, the completed steps will be retrieved. For each completed step, the related layer will be retrieved.

This results in the completed layers for an instance. Based on this information, it will be determined for each part (Top, Bottom, Through-Hole, Others) how many instances still must complete that part. The BOM will be used to make a list of the remaining components for a production process sheet. For each item on the BOM, the quantity of the item is multiplied by the number of products that remain to finish the part of the BOM item. As a result, a list of remaining components will be constructed.

8

Phase 5: Realize

The previous chapter described the system's design, including the system architecture, tools to be utilized, and an explanation of how the various features might be implemented. The fifth stage entails building the microservice in accordance with the design established in the previous chapter. The phases of the Scrum framework will be followed throughout the Realization phase. The Realization phase is separated into sprints, which are three-week iterations. The first section of this chapter provides an overview of the realization phase. Following that, each sprint has its own section in which the increment and evaluation are presented.

8.1 OVERVIEW

In total, two sprints of three weeks each could be completed. The first two sprints will be devoted to working on the features specified in the product backlog. Appendix L contains the product backlog, which is based on the user stories described in Section 6.3.2. After the second sprint, the product will be evaluated with stakeholders. A sprint review is held to assess the sprint's outcome and identify future adaptations.

8.2 SPRINT 1

8.2.1 Sprint progress

The first task completed during the first sprint was to set up a basic Flask web application. The project initialization included creating a directory for the program, configuring a Python virtual environment to install dependencies, and setting up the

Git repository. Following that, the application logic for a simple web application was created. The initial step was to create a Flask object that represented the app and then associate views with routes. Flask handles routing incoming requests to the appropriate view based on the request URL and the routes that have been established. The basic application that was constructed was running locally to ensure that everything was working properly.

The connection between the Flask application and the AEMICS core API was then established. The aemics api package was installed using Pip3, a package-management system for installing and managing software packages. The aemics_api package includes the module AemicsRequest, which makes it very simple to send requests to the API. The next step was to become acquainted with the API and determine how the data is structured and which requests are available.

The next step was to create a database to hold the inventory analyzer's data. A MySQL database was constructed and configured to run on an AEMICS server. Moreover, the extension Flask-SQLAlchemy was added to the application. The variable SQLALCHEMY DATABASE URI was defined, which is the connection string required to connect to the database. A database object was declared as a global variable, and the method `db.init app(app)` was used to pass the application as a parameter. In the application directory, a models.py file was created, and the db object was imported into it. A database model can be created by defining a class in the models.py file. Each new variable added to this model class correlates to a database column. Three different models were created:

- component_stock: To store the current stock of components
- component_stock_points: To store the inventory forecast
- component_minimum_stock: To store threshold inventory quantity of Kanban components

The component_stock_points table will be used to keep track of all points where a component inventory level is expected to change. A stock point is defined as any moment in time when the inventory level of a component is predicted to change. A stock point is defined as any moment in time when the inventory level of a component is predicted to change. A stock point exists because the component is expected to be employed in a manufacturing process or because it is expected to be delivered since it was ordered.

Following the connection to the database, a class named 'InventoryForecast' was created. Different GET requests are used to determine the stock points of a component. To determine the inventory forecast, the same approach as described in Section 7.3.3 was implemented in the class. The current component stock was determined using the quantities on carriers as indicated in Section 7.3.1. The component stock table is updated with the current stock of each component. Furthermore, the component minimum stock table was updated with the threshold inventory quantity for each Kanban component. A GET request to AEMICS' core API was used to determine the minimum stock.

The next stage was to create the inventory analyzer API, which allows an external service to send a simple command to the inventory analyzer in order to obtain data. The Flask-RESTful extension was used to establish a REST API. At the time, there was just one request with the parameter component_id, which returned all stock points for the specified component.

The data visualizations will eventually be developed in AEMICS' ERP. Before any code was added to the ERP system, it was tested locally and independently of the ERP system. An HTML webpage was constructed to accomplish this. The webpage sends requests to the inventory analyzer API and then creates a simple visualization based on the data received. The JavaScript-based library *Chart.js* was used to visualize the data.

Figure 24 shows the first version of the inventory analyzer. A component ID can be entered at the top, and when the request button is pushed, a GET request is sent to the inventory analyzer API. The returned data is displayed in a table on the right side. There are two stock points visible: an order that includes the component and a production process sheet in which the component will be employed. The title of the visualization displays the component ID from which the data was requested. Since it is a Kanban component, it has a minimum inventory level, which is shown in the subtitle. The red line at the bottom of the visualization also reflects the component's threshold inventory quantity. The first data point on the blue line represents the component's current inventory level. The following data points represent predicted inventory level changes. The reference ID associated with the inventory change is displayed on the y-axes. The 'Last update' date given at the bottom represents the date and time that the database was last updated. When the user hovers over a data point in the visualization, a tooltip with the quantity, reference ID, and expected date appears.

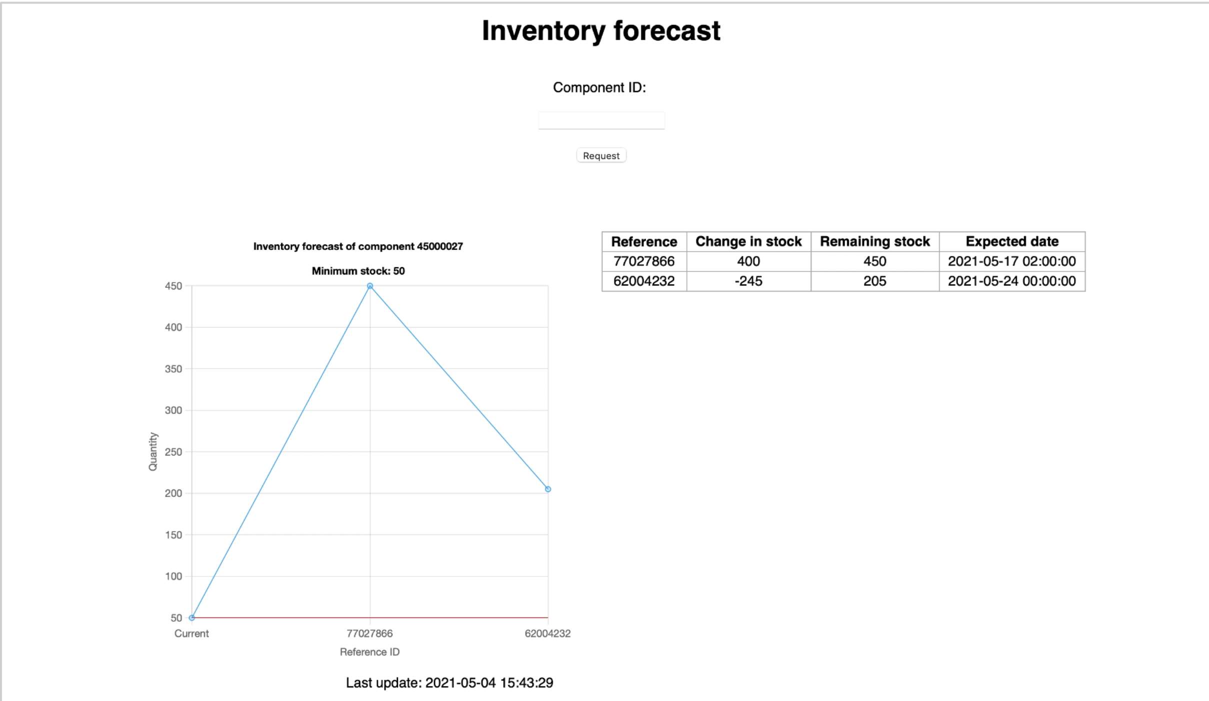

Figure 24. Version 1.1 of the inventory analyzer

The next step was to determine the historical inventory levels of a component. A new database model was added to the `models.py` file to store the historical inventory levels. Moreover, a new class was added called `InventoryHistory`. The approach as stated in Section 7.3.4 was used to determine the inventory history. A flowchart with code segments can be found in Appendix J. A new resource has been added to the API that provides the historical inventory levels of a component for which the ID is provided as a parameter in the request.

The HTML webpage was changed such that the visualization now includes the historical inventory levels of a component, as seen in Figure 25. The webpage sends three GET requests to the inventory analyzer API in this version: one to get the historical inventory levels, one to receive the current inventory level, and one to get the forecast. The table with the reference, stock change, remaining stock, and date has been moved below the visualization.

Figure 25. Version 1.2 of the inventory analyzer

At the end of the sprint, the latest version of the inventory analyzer was integrated into the ERP system. The inventory analyzer's back end was configured to run on an AEMICS server rather than locally. Docker was used to package and run the Flask application in an isolated environment. Moreover, the code of the ERP system was modified. The JavaScript code that sends requests to the back end of the inventory analyzer and creates visualizations based on this data was introduced to the ERP system. A Mako template was modified to include the HTML code. Finally, Pyramid was used to dynamically construct the ERP web pages.

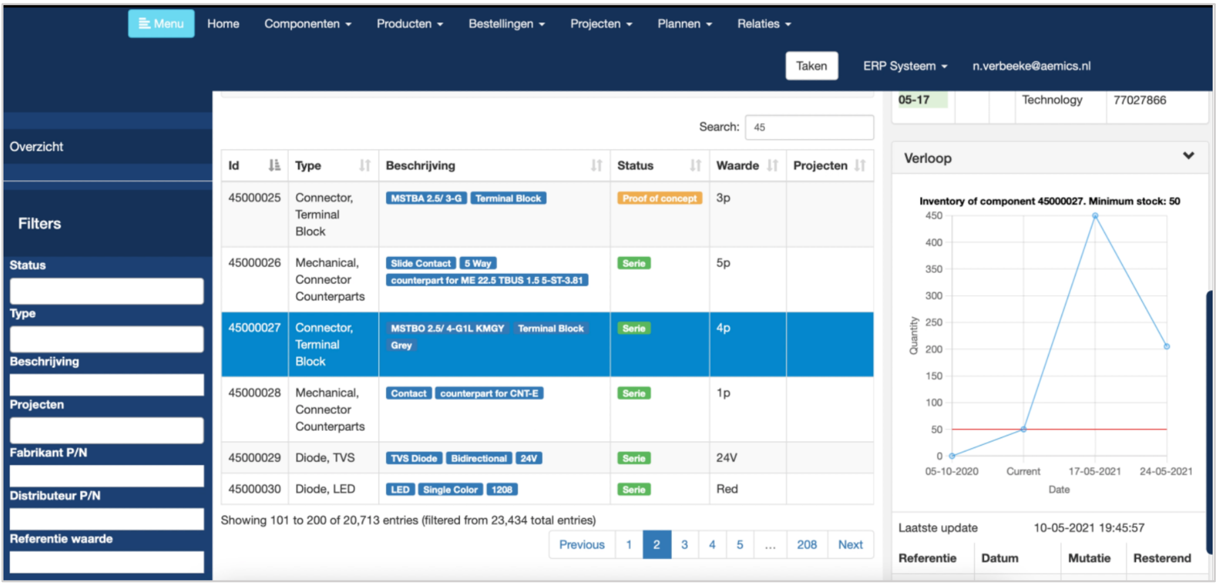

Figure 26. First release to the ERP

The ERP system is divided into six tabs, as detailed in Section 2.2.5. One of the tabs is 'Components' and clicking on it brings up a table with all of the components. When you click on a row in the table, a sidebar with information about the component will appear. This sidebar also includes the visualization of data from the inventory analyzer, as seen in Figure 26.

8.2.2 Evaluation

The inventory analyzer was successfully released to the ERP system at the end of the first sprint. One problem related to the component stock table was detected after the release. As described in the preceding section, the component stock table is updated with the current stock of each component. The current stock was determined every five minutes and was always added to the database. This results in a table that is rapidly expanding. The program was modified to address this issue. Instead of constantly adding the current stock of a component as a new row, the program now first checks to see if the component ID is already in the table. If the component ID already exists in the table, the row will be updated rather than adding a new row. A new row will be added only if the component ID does not already exist in the table.

The first release is a starting point for the next sprint, during which the application will be modified, and new features will be added. There were some conversations with stakeholders to determine if there were any requests for changes. A stakeholder highlighted that the way it is now visualized can be misleading. The reason for this is that it appears that the change in stock occurs over a period when, in fact, it occurred in a shorter period than visualized. Figure 27 depicts a screenshot that exemplifies this problem.

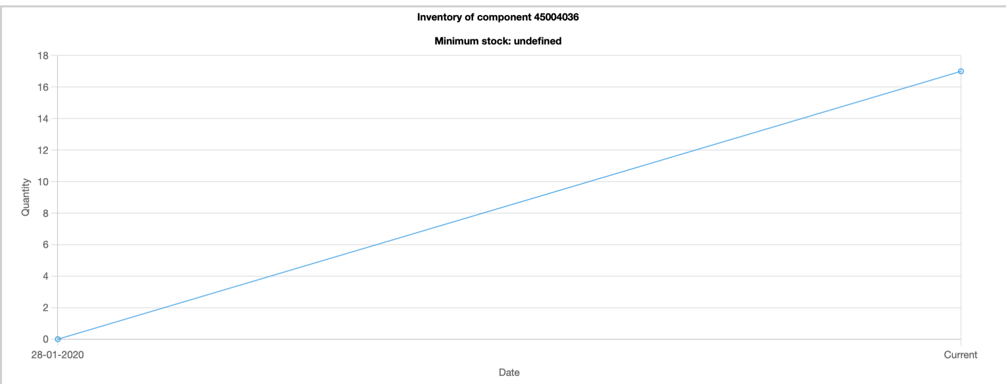

Figure 27. Example of a visualization that depicts a change in a component's inventory level

It can be observed that the inventory level of component 45004036 has increased between the 28th of January and the present. The visualization was created based on the inventory analyzer's response, which was as follows:


```
[
    {
        "component_id": 45004036,
        "change_date": "2020-01-28",
        "quantity_end_of_day": 17,
        "mutation": 17,
        "quantity_beginning_of_day": 0,
        "related_carriers": [
            90014448
        ]
    }
]
```


According to this response, the inventory level of component 45004036 grew from 0 to 17 on January 28th. Therefore, the rise should be depicted just on that day, followed by a constant line from the 28th of January to the present. The visualizations of the components will resemble a square wave. This modification will be implemented in the following sprint.

Another recommendation made by a stakeholder was to include a horizontal line indicating the current. In addition, instead of showing that the minimum stock is undefined, it should show that the minimum stock is 0.

The inventory analyzer determined the expected decreases in the inventory of a component based on the future manufacturing process sheets. The program accounts for the possibility of loss during the production process. In the best-case scenario, there will be no loss at all. One stakeholder proposed including a line that represents the best-case scenario in the visualization. If the worst-case inventory forecast, which includes losses, shows that there is insufficient of a component to complete a production process sheet, the best-case inventory forecast may be used. If there is enough of the component to complete the production process sheet in the best-case scenario, it may be considered to start the production. In that case, the manufacturing team should endeavour to minimize product loss. The best-case scenario will be added to the inventory projection during the second sprint.

8.3 SPRINT 2

8.3.1 Sprint progress

The evaluation that occurred following the first sprint resulted in certain changes that were applied during the second sprint. The inventory level change of a component is now displayed on a single day, as mentioned in the preceding section. A grey horizontal line was also added to denote the current day. Figure 28 depicts a screenshot of the new version developed at the start of Sprint 2.

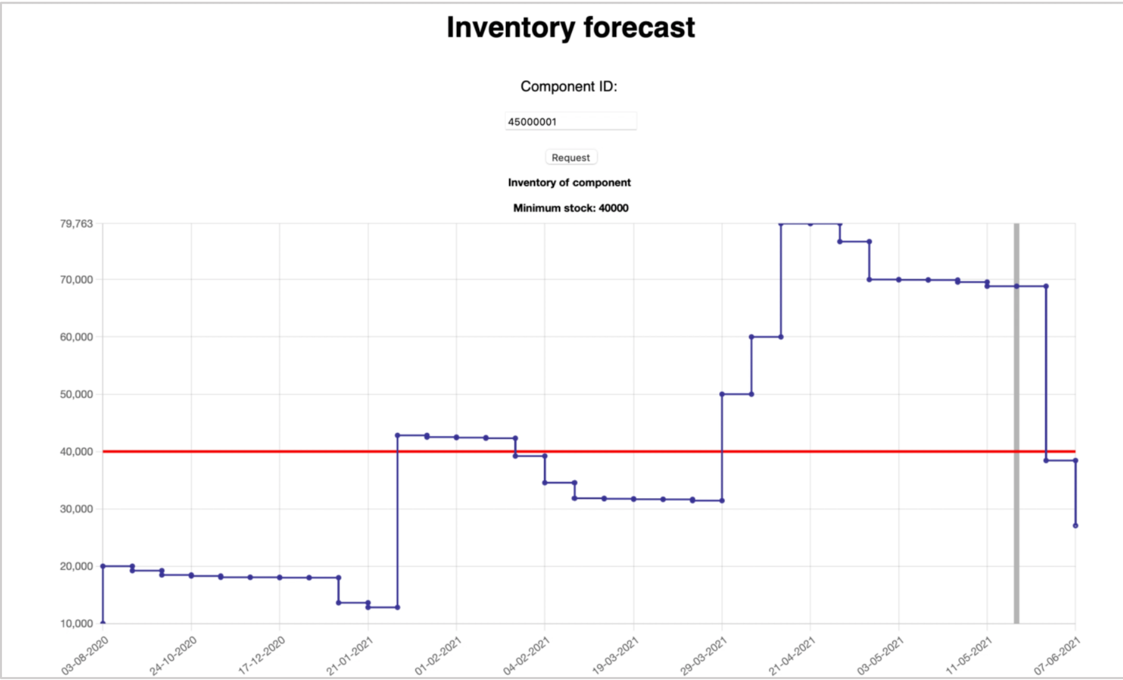

Figure 28. Version 2.1 of the inventory analyzer

Version 2.1 was shown to stakeholders, and a discussion ensued on the number of data points that should be displayed in the visualization. As seen in Figure 28, some components have a large number of historical data points. A visualization with an excessive number of data points can be overwhelming and may fail to provide a clear picture. It was considered to just eliminate data points from the visualization and only show the most recent data points. The drawback is that data points that may contain important information are deleted. Therefore, it was determined to investigate better options.

One option is to redesign the data visualization. Currently, the visualization depicts the stock change over a day, so the first data point is the quantity at the start of the day and the second data point is the quantity at the end. It is possible to filter it by week rather than by day. However, only showing the quantity at the beginning and end of the week may leave out critical information. As a result, it was decided to display the lowest and highest inventory levels of a component each week. The lowest and highest levels are very helpful in determining whether a component has fallen below the Kanban inventory level in that week.

In terms of the inventory forecast, no information should be left out and the data points should be displayed as before. In other words, the inventory forecast data points should be displayed per day. The latest version of the inventory analyzer displayed both historical and expected inventory levels in the same visualization. The way historical inventory levels are displayed has been altered to the minimum and maximum each week, while the inventory forecast data points are still displayed per day. As a result, the graph is inconsistent, which can be deceptive and confusing. To avoid making a misleading data visualization, the inventory history and forecast were separated into two separate visualizations.

The inventory analyzer, as described at the end of Section 8.2.2, should also display the best-case scenario. The best-case scenario was determined in the same manner as the worst-case scenario. The only difference is that the code lines containing the dropout and loadloss should be eliminated in order to establish the best-case scenario.

The latest version of the inventory analyzer was integrated into the ERP system at the end of the sprint. Docker was utilized again to package the Flask application. The Mako template and JavaScript code in the ERP system were also updated. Figure 29 displays a screenshot of the result after the inventory analyzer was released to the ERP system.

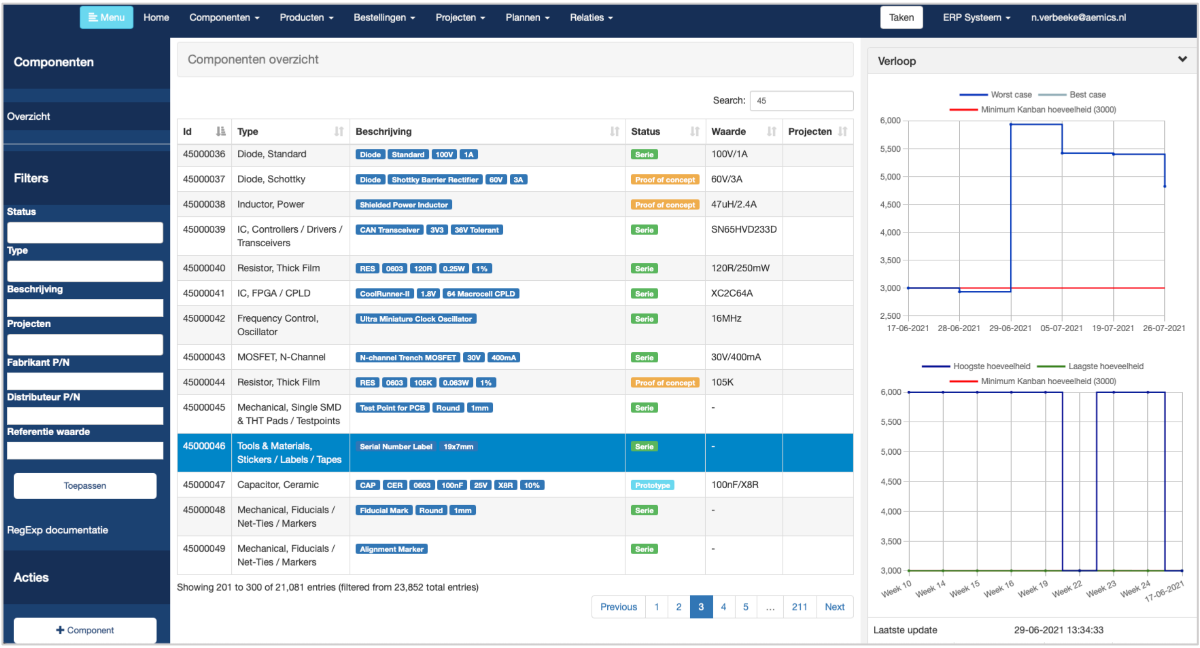

Figure 29. Second release of the inventory analyzer to the ERP system

After the second sprint, the focus will be on product evaluation and documentation. The following chapter will go over the results of the evaluation in detail. There were recommendations made that AEMICS could consider implementing in the future. These recommendations will be discussed in Chapters 9 and 10.

9

Phase 6: Evaluate

The final stage of the design process involves evaluating the final product developed for this graduation product. The first section presents to what extent the functional requirements correspond to the final product. Following that, the results of the questionnaire and semi-structured interviews will be presented.

9.1 EVALUATION OF REQUIREMENTS

As can be seen in Table 3, the application satisfies all requirements.

Criteria	Satisfied
• The system should be able to provide the expected changes in a component's inventory level.	✔
• The system should be able to determine the remaining components of a production process sheet.	✔
• The system should be able to determine the current inventory level of a component.	✔
• The system should be able to return the history of a component's inventory level.	✔
• The system should be able to return the minimum Kanban quantity of a Kanban component.	✔

Table 3. Overview of satisfied functional requirements

9.2 USER EXPERIENCE EVALUATION

9.2.1 Research design

The preceding chapter described how the inventory analyzer visualizations were implemented in the ERP system. The inventory analyzer may have a positive impact on AEMICS, but its success is dependent on acceptance and behavioural intent to use. The success of the application considerably depends on the acceptance of its actual users, i.e., AEMICS personnel. Therefore, it is important to explore the determinants of acceptance as well as the behavioural intention to use the inventory analyzer visualizations. To accomplish the aforementioned objective, the Unified Theory of Acceptance and Use of Technology (UTAUT) model [49] will be adopted during the evaluation phase. Two constructs were adopted from the UTAUT: performance expectancy and effort expectancy.

Another goal of this evaluation is to look at the user experience (UX) of the inventory analyzer visualizations. To achieve a comprehensive view of the UX of the inventory analyzer visualizations, the modular evaluation of key Components of User Experience (meCUE) questionnaire [52] was adopted. The following items of meCUE were adopted: usefulness, usability, and visual aesthetics

A self-administered questionnaire and semi-structured interviews will be used as research instruments. Those will be discussed in the following section.

9.2.2 Research instrument: questionnaire

The questionnaire was designed based on the questionnaire items of the UTAUT and the meCUE questionnaire. Appendix M contains the entire questionnaire. The questionnaire will be distributed to all employees, regardless of whether they have used the inventory analyzer. Since the inventory analyzer will be integrated into the ERP system, it is accessible to all employees. A brief tutorial will be offered at the start of the questionnaire to familiarize the respondent with the inventory analyzer. Following the tutorial, the respondent will be instructed to find the inventory analyzer in ERP. The respondent will be asked if the inventory analyzer could be found. The questionnaire will be terminated if the participant indicates that he or she was unable to locate the inventory analyzer in ERP. This is because viewing the visualizations prior to answering the questionnaire is a prerequisite.

The respondent will then be asked a multiple-choice question about his or her position at AEMICS. Following that, the participant will be asked a multiple-choice question to indicate how frequently they use the inventory analyzer visualizations. If the participant states that he or she rarely or never uses the inventory analyzer, the next questions will be skipped until the Performance Expectancy General section.

Otherwise, the participant is asked to explain why they are using the inventory analyzer and describe their most recent use. The participant is also asked to indicate how much he or she agrees with the statements in the section Performance Expectancy Individual.

The following sections are Performance Expectancy General, Performance Expectancy Procurement, and Performance Expectancy Production. In these sections, statements will be provided that will be utilized to assess the expected performance of the inventory analyzer on AEMICS in general, the procurement team, and the production team.

Following that, statements will be provided to evaluate the effort expectancy. The following question asks the participant if he or she expects to use the inventory analyzer in the coming month. Subsequently, four statements will be provided to assess the visual aesthetics of the visualizations. The participant is then asked what may be done to improve the inventory analyzer and whether the inventory analyzer currently provides all of the information required for inventory.

The next section is about the remaining components table. The table of remaining components is located in a different part in ERP than the inventory level visualizations. To avoid confusion, the questions regarding the remaining components table are asked at the end of the questionnaire. The participant will initially be asked if he or she has ever utilized the table of remaining components. If not, the section that follows is skipped. If the participant has utilized the remaining components table, statements will be provided to assess the performance expectancy of the remaining components table. Finally, it will be asked whether there is anything that might be done to improve the table of remaining components.

9.2.3 Research instrument: interview

Following the questionnaire, semi-structured interviews will be held to conduct qualitative user research. The prepared interview questions are partially based on questions provided by Doody [63]. In addition, several questions were adapted from a set of questions provided by Nguyen [64]. Appendix N contains the questions prepared for the semi-structured interviews. The interview questions are divided into sections which are: position within AEMICS, goals, context of use, and user experience.

9.2.4 Results questionnaire

Participants

The questionnaire was distributed to all employees. Thirteen of the twenty employees completed the questionnaire. Everyone who completed the questionnaire stated that they were able to access the inventory analyzer visualizations in the ERP system. Employees from various roles within AEMICS completed the questionnaire. Employees from the development department, the production department, a purchaser, the CEO or executive assistant, and the operational manager were among those who responded. One of the respondents indicated that he works as both a purchaser and an operational manager. The pie chart in Figure 30 depicts the distribution of respondents by position at AEMICS.

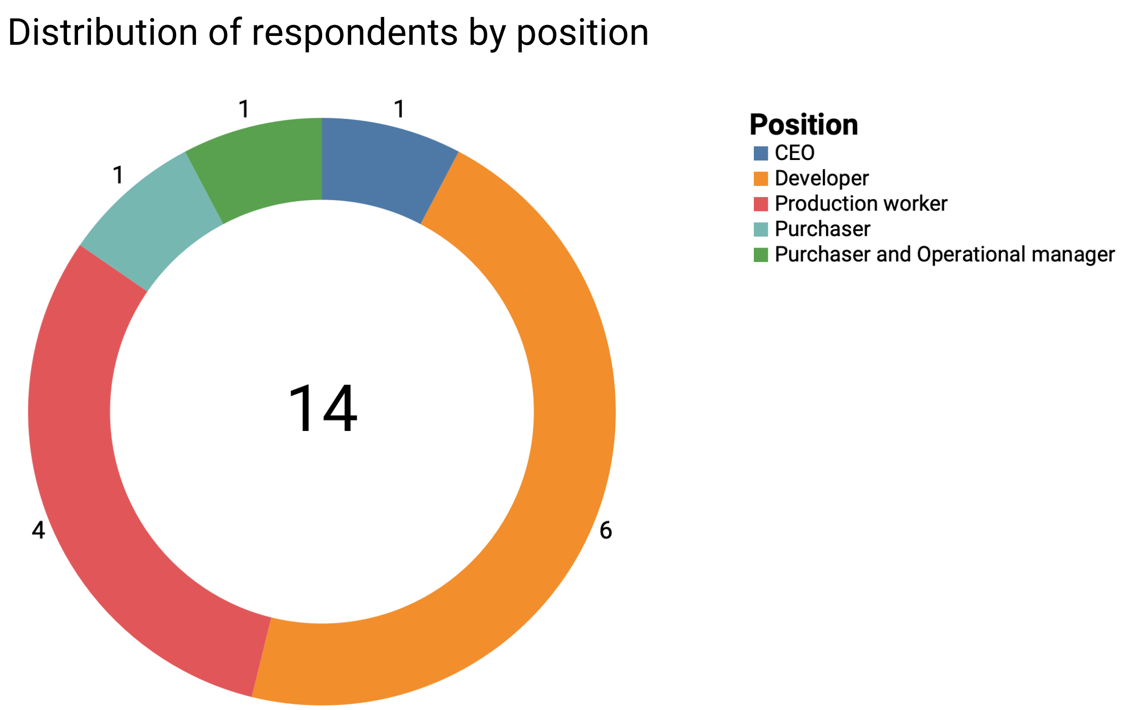

Figure 30. Visualization of the distribution of respondents by position

Use frequency

The frequency with which the inventory analyzer is used varies from person to person. Four of the respondents, all developers, said they rarely or never use the inventory analyzer. One developer stated that he uses the inventory no more than once a month. One developer and one production worker said they used the inventory analyzer at least once a month, but not weekly. Six respondents indicated that they use the inventory analyzer weekly, and three of those six said they use it daily. The inventory analyzer is used on a daily basis by both purchasers and one production worker. Figure 31 depicts an overview of use frequency by position at AEMICS.

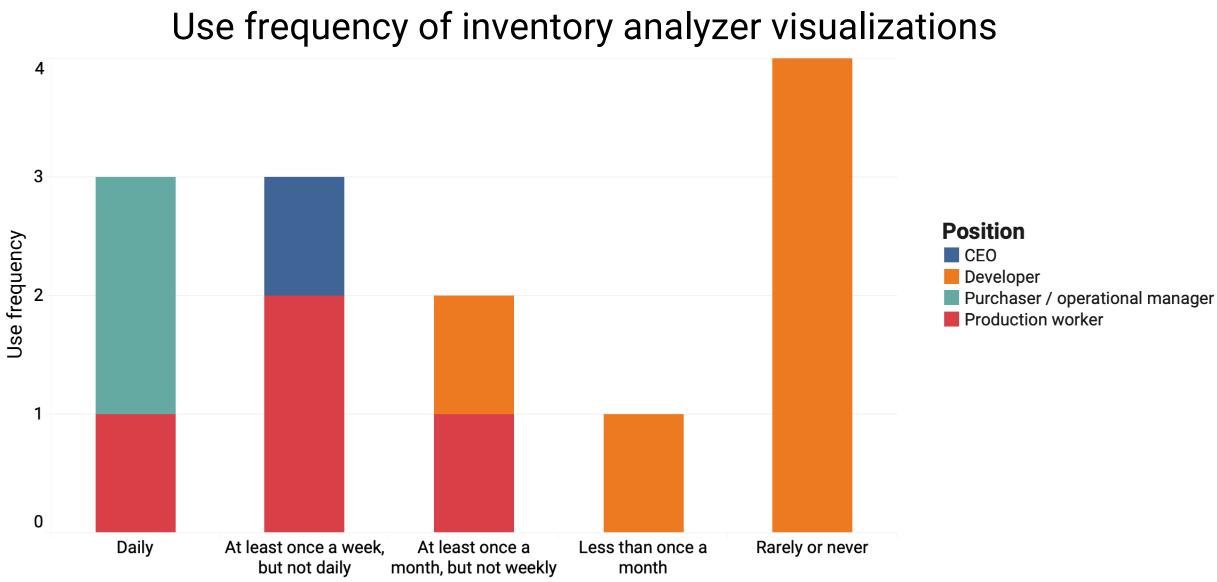

Figure 31. Overview of use frequency by position at AEMICS

The inventory analyzer is utilized for a variety of reasons. One respondent mentioned using the inventory analyzer to acquire insight into expected changes in inventory levels of specific components. The inventory analyzer, according to the operational manager, was useful in determining whether it was essential to purchase components after a production process sheet was scheduled. Another responder noted that the inventory analyzer may be used to determine whether a component has enough stock to be used in the manufacturing process. It was also mentioned that the inventory analyzer could provide a clear picture of a component's future consumption. If there is a strange mutation of a component, the inventory analyzer is also used to retrieve further context. It was also noted that when quotations are prepared, the inventory analyzer is used to check what is in stock if a component is difficult to obtain. One of the production workers remarked that the inventory analyzer can be used to determine whether there is enough stock to finish a production process sheet. Furthermore, one of the buyers noted that the inventory analyzer is a tool that helps with component procurement.

One of the questions asked the responder to recall the most recent time they used the inventory analyzer. According to one of the production workers, the inventory analyzer was just deployed and hence is not being used very frequently at the moment, but it is expected to be utilized more in the future. Another production worker mentioned utilizing the inventory analyzer after machine assembly to examine the remaining components. During the most recent use of the inventory analyzer, one respondent remarked looking at the red line (Kanban stock) and the fluctuations in the blue line (inventory level in future). This assisted in determining how much of this particular component needed to be purchased. Another responder stated that the inventory analyzer is always used during the procurement process. The inventory analyzer was mentioned as a tool for identifying potential component shortages. Furthermore, the inventory analyzer assists in determining whether a component's inventory level is below the minimal Kanban threshold, indicating that the component should be obtained. One of the responders noted that the most recent use was to explain to a client how AEMICS handles inventory management.

Performance expectancy

The questionnaire looked at the degree to which the participant believes that using the system will help him or her to attain gains in job performance. This is known as the performance expectancy. Performance expectance was assessed for the following categories: individual, AEMICS in general, procurement, and the production team. Figures 32-35 show divergent stacked bar charts depicting the distribution of the level of agreement by statement for each category. The black circles in those figures represent the average score for each statement. The average score is computed by summing the numerical value of each response and then dividing it by the total number of respondents. The numeric value ranges from 1 (strongly disagree) to 5 (strongly agree).

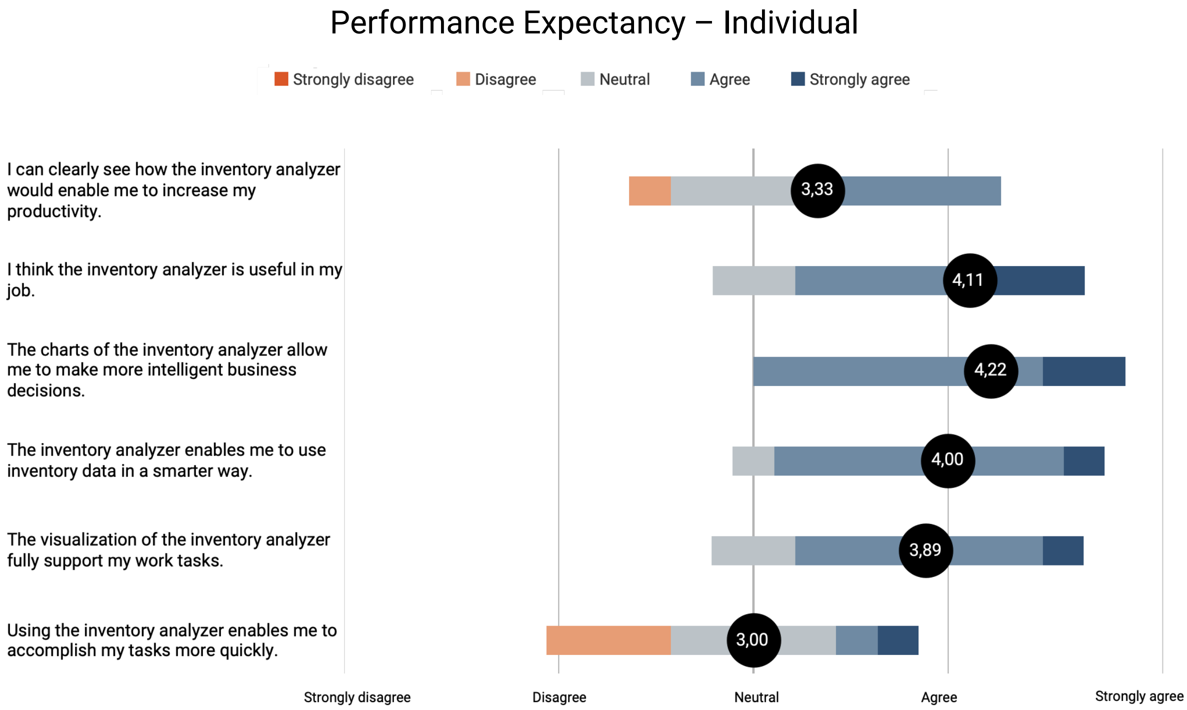

Figure 32. Visualization of questionnaire results in the category 'Performance Expectancy: Individual'

The category 'Individual' assesses the performance expectancy of AEMICS personnel who use the inventory analyzer visualizations. All users agree that the inventory analyzer visualizations help them make better business decisions. The majority of users believe that the visualizations are useful and assist them to make better use of inventory data. On average, respondents do neither agree nor disagree that visualizations help them complete their tasks more quickly. Four out of nine respondents say that they can clearly understand how the visuals help them to be more productive.

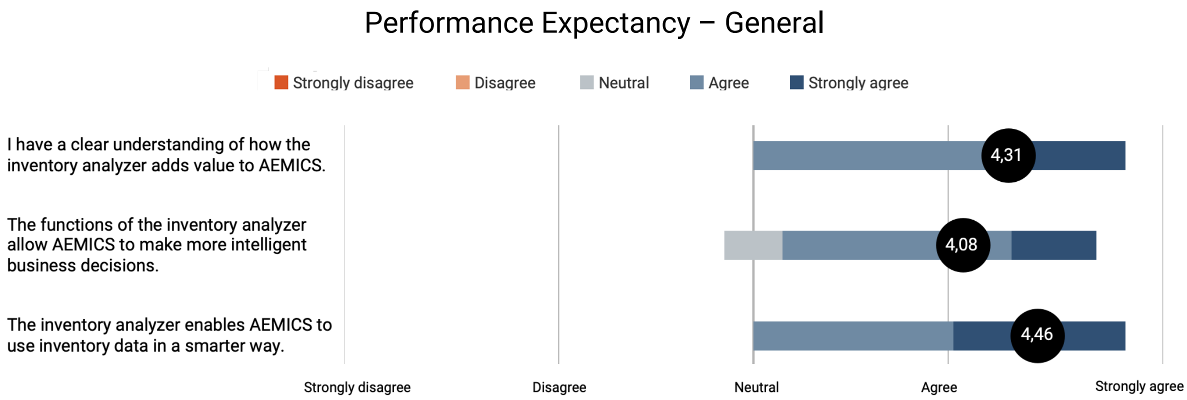

Figure 33. Visualization of questionnaire results in the category 'Performance Expectancy: General'

According to the results in the category 'General', respondents agree that the inventor analyzer helps AEMICS enhance its performance. All responders believe that the inventory analyzer provides value to AEMICS and enables AEMICS to make better use of inventory data. Furthermore, the majority of respondents feel that the inventory analyzer's functions enable AEMICS to make more intelligent business decisions.

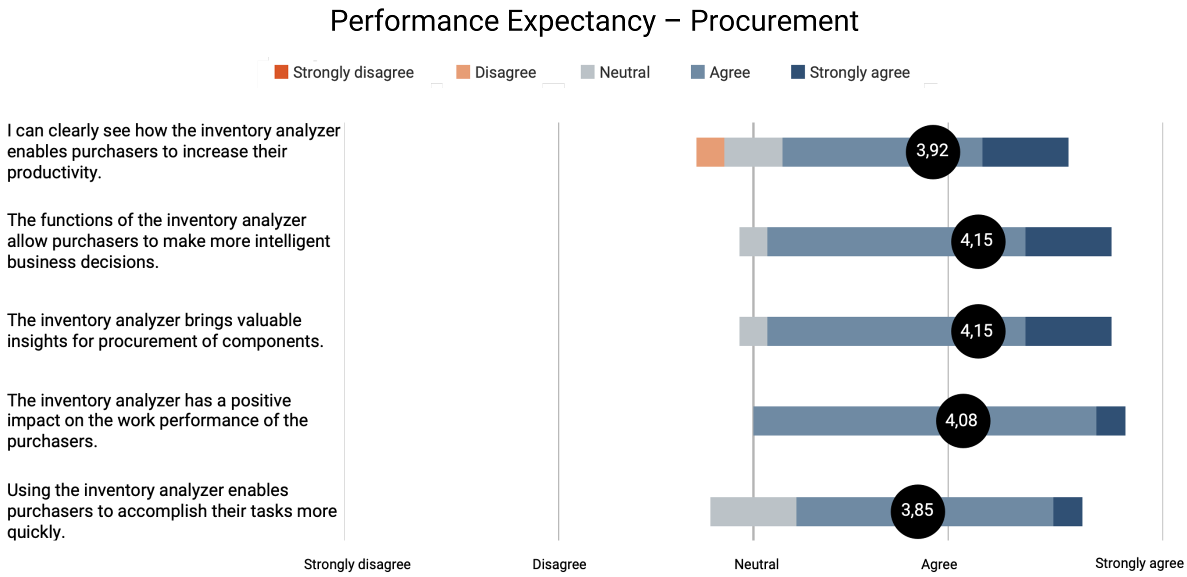

Figure 34. Visualization of questionnaire results in the category 'Performance Expectancy: Procurement'

The results in the category 'Procurement' reveal that respondents agree that the inventor analyzer assists the procurement of AEMICS in improving its performance. The majority of respondents believe that the inventory analyzer increases purchaser productivity and allows purchases to complete their tasks more quickly. All responders agree that the inventory analyzer has a beneficial impact on the purchasers' work performance. Furthermore, respondents generally think that the inventory analyzer provides valuable insights for procurement and enables purchasers to make more intelligent business decisions.

The category 'Production team' assesses the performance expectancy of the production team. Opinions differed on whether the inventory analyzer increases the production team's productivity. The majority of respondents felt that the inventory analyzer provides valuable information and helps the production team in making more intelligent decisions. Moreover, six out of thirteen respondents feel that the inventory analyzer has a beneficial impact on the work performance of the production team. One person disagrees with this statement, while the other six are neutral.

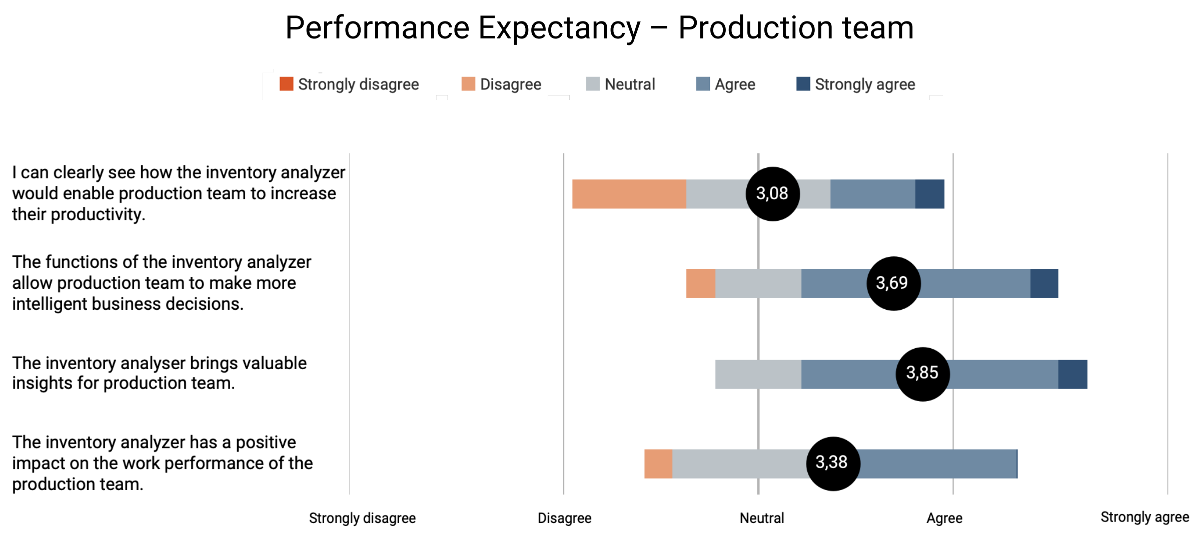

Figure 35. Visualization of questionnaire results in the category 'Performance Expectancy: Production team'

Effort expectancy

Following the performance expectancy, statements related to the effort expectance were given. The effort expectancy looks at the degree of ease associated with the use of inventory analyzer visualizations. Figure 36 depicts visualizations of the level of agreement distribution by statement.

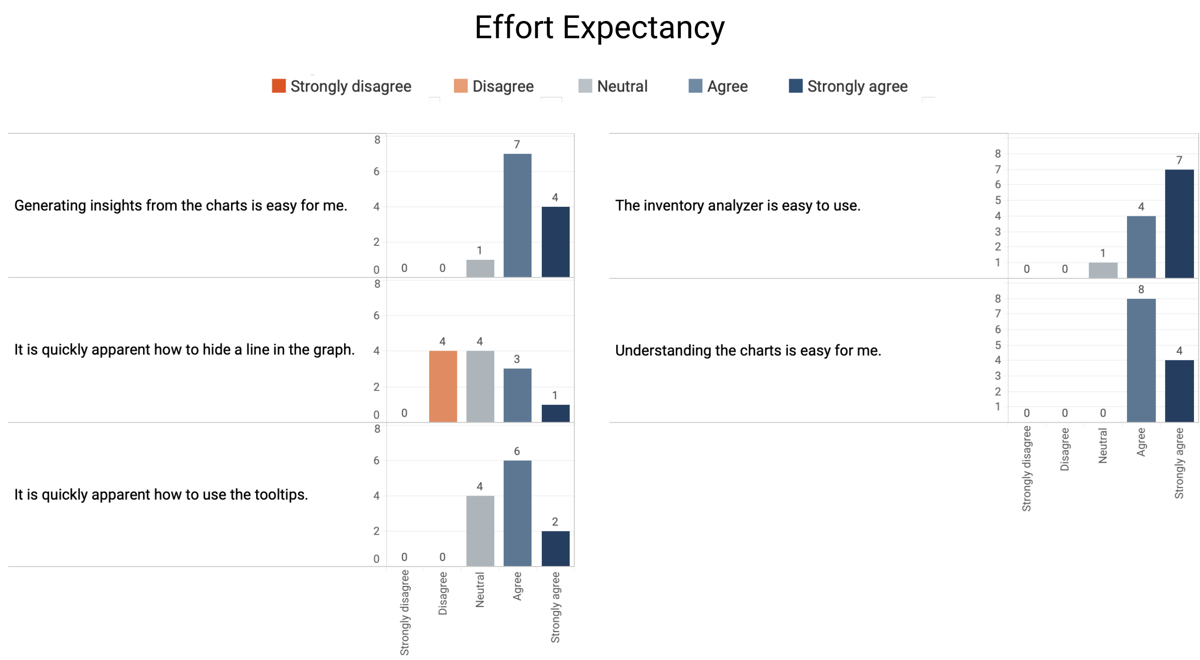

Figure 36. Visualizations of questionnaire results in the category 'Effort expectancy'

The majority of respondents feel that the inventory analyzer visualizations are easy to understand and that generating insights from them is simple. The results show that the inventory analyzer is easy to use and the use of tooltips is straightforward. Four of the twelve respondents stated that it is not immediately obvious how to hide a line in the graph.

Behavioural intention to use

The respondent was then asked whether he or she planned to use the inventory analyzer visualizations in the coming month. Ten of the thirteen respondents said they plan to use the inventory analyzer in the coming month. Three respondents stated that they do not expect to use it in the approaching month. Figure 37 depicts the percentage distribution of this outcome.

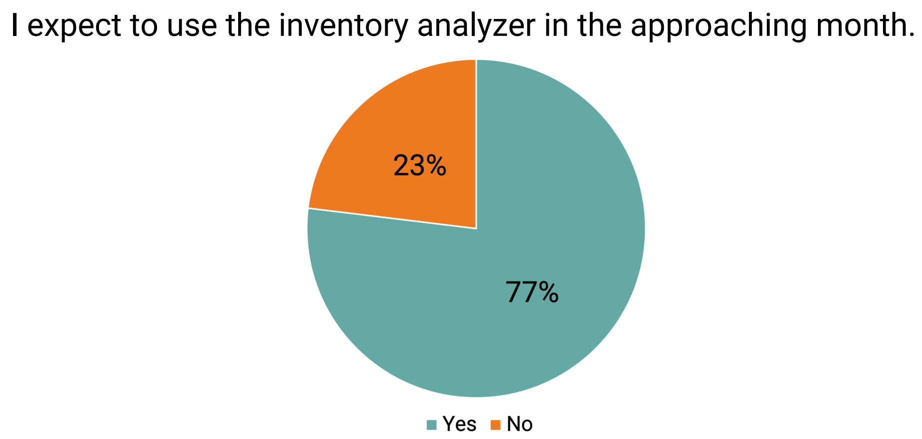

Figure 37. Distribution of intention to use the inventory analyzer

Visual aesthetics

Figure 38 depicts the outcomes related to the visual aesthetics of the inventory analyzer visualizations. The majority of respondents are undecided about whether the inventory analyzer stands out in terms of design when compared to other software products in the organization. The respondents' opinions on whether the inventory analyzer contains creative design elements differ. Two respondents do not recognize elements of a creative design in the inventory analyzer, and five are neutral. Six respondents, on the other hand, said that they could recognize elements of a creative design in the inventory analyzer. The majority of responders think the inventory analyzer visuals are stylish and attractive.

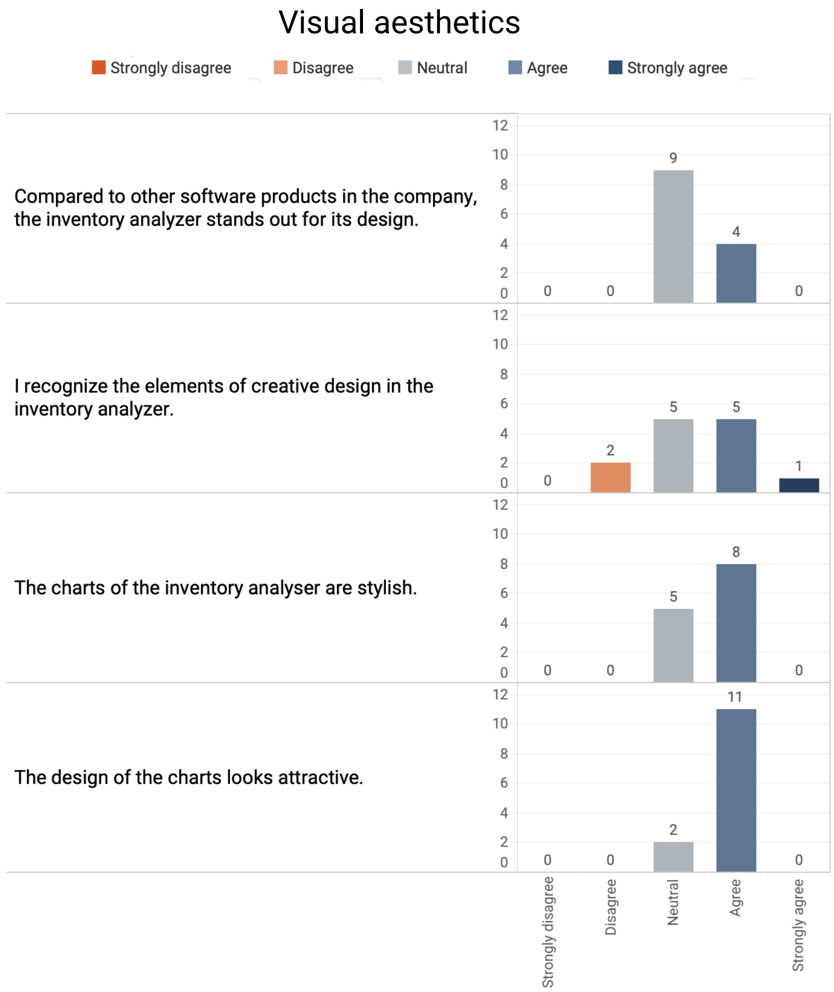

Figure 38. Visualizations of questionnaire results in the category 'Visual aesthetics'

Remaining components table

The questions about the remaining components table were only shown to production workers because they are the ones who use the table. Four production workers completed the questionnaire, and they all stated that they had used the remaining components table at some point. According to one of them, the remaining components table is not useful for his or her job. Three other respondents, on the other hand, agreed that the remaining components table is useful in their job. Two of the four respondents agree that the remaining components table helps them make better decisions. Furthermore, two respondents felt that the remaining components table helps them complete tasks more quickly. Appendix O contains the complete results of the statements relating to the remaining components table.

Improvements

There are several possible improvements mentioned by the respondents. One of them proposed using data mining in the forecasting of component inventory levels. Another point was about the x-axes of the visualizations. Both visualizations show the time on the x-axes, but one shows it as a week number and the other one provides a date. It was mentioned that it is possible to lookup how those two are related in the calendar, but this is time-consuming and inconvenient. Another suggestion was to send an email if the inventory level of a Kanban item falls below its threshold. A respondent noted that in the history chart, another line of average inventory levels may be added because the lowest and highest values can be difficult to interpret. Furthermore, it was suggested that a help function be implemented. This help tool might explain, for example, the distinction between worst-case and best-case scenarios in the inventory forecast. Furthermore, the help tool might explain which interactions with the charts are possible. It was also claimed that if the mutations are tiny, it can be difficult to detect them. As a result, adding a zoom button could be a good idea. When a component has a large number of data points, the inventory history display can get cluttered with information, making it difficult to read.

9.2.5 Results interviews

Two semi-structured interviews were conducted with AEMICS employees. The first interview was with the purchaser. She stated that the main goal of her job is to ensure that components are ordered on time and delivered before they are needed. The mistake that could be prevented if you had the appropriate data is that components are delivered too late, causing problems with planning. She mentioned that she needs current inventory levels, components related to production process sheets, and supplier information on a daily basis. Supplier information includes the costs of the components as well as whether or not the component is available. The supplier information is used to determine where the component will be ordered. She stated that she did not use the inventory history visualization very much, but that she intends to use it more in the future. She frequently employs the inventory future visualizations to examine the anticipated changes in inventory levels. She noted that seeing the expected negative changes is useful since it allows her to order components that will be needed in a few weeks. It was also highlighted that the inventory analyzer is a useful tool for getting a quick overview of a component's inventory levels and for anticipating projected changes in the inventory level. During the interview, it was mentioned that the inventory history visualization sometimes contains too many data points, making it difficult to interpret. She remarked that if there are too many data points, she frequently skips through the inventory history visualizations. Furthermore, the colour of the worst-case and best-case lines in the inventory forecast visualizations can be difficult to differentiate. A recommendation was made to include the ability to view the lowest and highest inventory levels each month. Moreover, the colours of the worst-case and best-case lines in the inventory forecast visualizations are sometimes difficult to distinguish.

The second interview was with an AEMICS employee who is the operational manager and also in charge of purchasing components. An important goal in his job is to ensure that components are supplied on time to AEMICS in order for the production process to begin on schedule. Another goal is to have the products delivered to customers on time. The mistake that could have been avoided if you had the necessary data is that you do not miss out. The inventory analyzer allows you to see if there are enough components for a manufacturing process sheet right away. Long-term planning is also possible using the inventory analyzer. On a daily basis, he needs to know the current inventory levels and the expected use of components. He stated that the inventory analyzer visualizations help him decide whether or not to adjust the sprint planning. Furthermore, the visualizations assist in placing large orders and reserving inventory at a supplier. A recommendation was made to provide a trigger when a component is not delivered on time. He noted that a common issue is that a production worker forgets to record when a component was used in the manufacturing process in ERP. He suggested that it could be a good idea to check whether the quantity recorded by a production worker matches the expected quantity. Another recommendation was to automatically display the last three months in the inventory history visualization. A feature that allows the user to specify the time period for which they want to look back in history could be implemented. He also suggested that the Kanban minimum threshold could be based on the actual consumption of a component.

9.2.6 Limitations

Regarding the limitations of the interviews, it could be argued that the presence of the interviewer may influence the respondent. As a result, the respondent may provide fictitious information in order to make the interview more interesting. The respondent may also become emotionally involved with the interviewer and provide responses that he or she believes would delight the interviewer. Since there is no anonymity, the presence of the interviewer may also restrict free responses. The respondent may be hesitant to provide responses for fear of tarnishing his or her image.

One limitation related to the questionnaire is the small sample size, which may make it difficult to determine if a particular outcome is a true finding. A small sample size also has an impact on the reliability of the questionnaire results since it causes more variability, which may lead to bias.

The questionnaire and interviews were both conducted in Dutch, which is the native language of AEMICS employees. The outcomes are translated into English, which may be a limitation. For example, because it is theoretically possible that some of the translation is ambiguous.

10

Conclusion

The following chapter presents the conclusion of this graduation project. The first section provides an outline of the conclusions as well as an answer to the research question. An evaluation of the design process will then be presented in the second section. Finally, several recommendations for further work are provided.

10.1 CONCLUSIONS

The aim of this graduation project was to design a tool for analysing and visualizing data in order to derive value from the inventory data available at AEMICS. The main purpose of the tool is to enhance the effectiveness and efficiency of inventory management at AEMICS. The main research question of this project was:

In what way can data analytics be used to improve inventory management at AEMICS?

A literature review was conducted to explore the opportunities regarding the use of data analytics for inventory management. Reviewed studies into the topic of inventory management demonstrate that enhancing an organization's inventory management can significantly improve the quality of the outcome of business performance. The reviewed studies claim that data analytics can help organizations face several challenges with inventory management, such as underproduction, overproduction, stockout situations, raw material supply delays, and inventory discrepancies. The literature review confirmed that data analytics can be used to enhance information extraction and decision-making in inventory management.

A design process was developed to outline the phases that will be followed in this graduation project. To fit the context of this graduation project, it was decided to combine the Design Thinking model and the Creative Technology Design Process. The design process of this graduation project consists of five phases: (1) Empathise, (2) Ideate, (3) Converge, (4) Realize, and (5) Evaluate. Stakeholders were actively involved in each of these phases.

During the realization phase, the Scrum framework was utilized to iteratively and incrementally create the product. An application called inventory analyzer was created as part of this graduation project. The application can determine and return current inventory levels, historical inventory levels, expected changes in a component's inventory level, minimum Kanban quantities, and the remaining components of production process sheets. An API was added to the inventory analyzer ensuring that an external service may issue a simple command and the inventory analyzer will respond with the requested data. The ERP system sends requests to the inventory analyzer API, and visualizations are provided based on the results.

Since the initial release to the ERP system, the inventory analyzer has been used by AEMICS employees. It is used by employees in various positions within AEMICS, including purchasers, production team, operational manager, and CEO. Purchasers always use inventory visualizations while acquiring components. The inventory forecast, in particular, since it provides a clear picture of the expected changes in component inventory levels.

Based on the findings of the evaluation, it is possible to infer that the inventory analyzer is a tool that improves inventory management at AEMICS. Therefore, the conclusion can be drawn that establishing a tool that analyses and visualizes data is a way to leverage data analytics to improve inventory management at AEMICS.

10.2 EVALUATION OF THE PROCESS

The design method utilized in this graduation project will be evaluated in this section. The involvement of stakeholders throughout the phases is a crucial aspect of the design process. It is critical to involve the people for whom you are designing in order to create something that will be used by them.

The empathise phase ensures that the designer first completely understands the stakeholders' feelings, needs, motivations, and emotions. During the empathise phase of this graduating project, it was decided to organize group meetings with stakeholders. Stakeholders were prompted to write down any existing inventory management difficulties during these sessions. These sessions assisted in collecting the inventory management issues that AEMICS is now dealing with.

Asking participants to write down their ideas helped to engage everyone in the session and allowed everyone to think for themselves. The group sessions also offer a way to look at situations from different angles. However, those group sessions did have certain drawbacks. The writing on the sticky notes was quite brief and lacking in information, which made it difficult to understand what was meant. Since there were many sticky notes, going over each one individually would have taken too long. There are several issues that are encountered by several employees and, as a result, are written down multiple times. Since similar problems were stated in different ways, it was difficult to connect the sticky notes that were related to the same problem. Even though it was stated in advance that the difficulties should be related to inventory management, quite a few problems were out of scope. An improvement could be to give the participants a clear and narrowed-down question that asks for problems connected to a specific category. In the instance of this graduation assignment, rather than asking participants to write down any inventory management problems, the question could be broken down into smaller questions or categories. For example, ask participants to write down ideas related to purchasing. Another improvement could be that, in addition to the person leading the group session, there should be a notetaker who can jot down important information.

As part of the ideation phase, co-creation sessions were organized in this project. Participants in the co-creation sessions were encouraged to come up with solutions for addressing one or more of the inventory management challenges that are currently being encountered. The co-creation sessions were beneficial in terms of producing several ideas and including stakeholders in the process of developing ideas. One problem was that the ideas were written down very concisely, making it difficult to understand what the participants intended. The ideas were quite diverse, and they addressed many different issues. An enhancement would be to choose which problem should be addressed in the project before the ideation phase. In the case of this project, the results of the empathise phase group sessions should be narrowed down to one specific problem. This problem might then serve as the beginning point for the co-creation session. As a result, the ideas generated during the co-creation session are likely to be more easily combined. Furthermore, similar to the improvement indicated for group sessions, including a notetaker in the session could be helpful.

Participants were instructed to write on sticky notes in both the group sessions during the empathise phase and the co-creation sessions. An important lesson learned is that it is very advantageous to group similar sticky notes and use an additional sticky note to write down the category to which those sticky notes are related. Matrices were utilized as a technique for assessing problems or ideas. Rather than placing each sticky note in a matrix, the decision might be taken to place the overarching sticky note on the matrix. Both the importance/effort matrices, as well as the potential/feasibility matrices, were quite useful. It was interesting to observe the discussions between stakeholders about the placement of a sticky note on the matrix.

The Scrum framework was adopted in the realization phase. Due to the restricted time available for implementation, only two sprints were carried out in this graduation project. Using the Scrum framework was beneficial since it focused on providing a usable increment after each sprint. An increment delivered at the end of the sprint can be reviewed, and feedback from stakeholders can be obtained.

10.3 FUTURE WORK

In future work, the inventory analyzer application could be improved and expanded with new functionalities. It could be interesting to estimate losses based on the actual component dropout and loadloss. The mismatch between the system and reality may be worth investigating in the future. When an employee registers a mutation, a feature might be added that automatically checks to see if the mutation is as expected. Inventory forecasting could be an important area for future research. Opportunities for data mining in component inventory forecasting could be examined. There are also some fascinating ideas related to Kanban items that could be included in future work. If the inventory level falls below the Kanban minimum threshold, a trigger could be sent to the purchasers to notify them that they need to reorder the component. The Kanban minimum threshold could be adjusted based on the component's consumption in the past. In conclusion, the inventory analyzer application provides a good starting point for discussion and further research.

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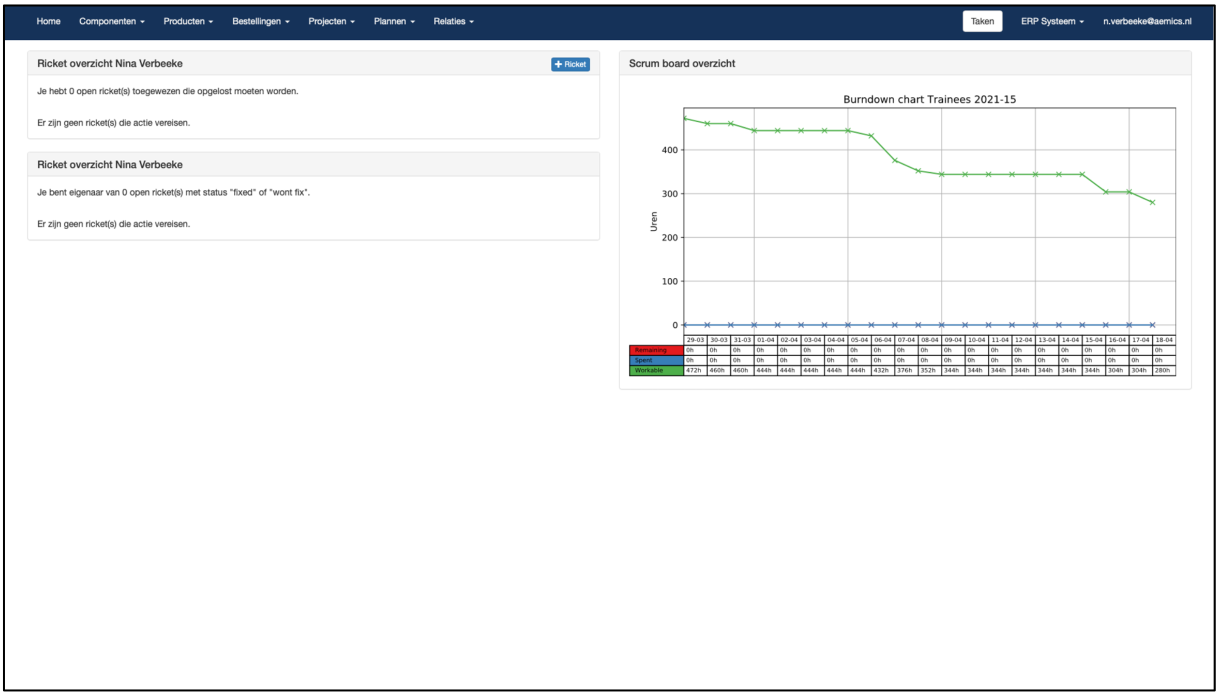
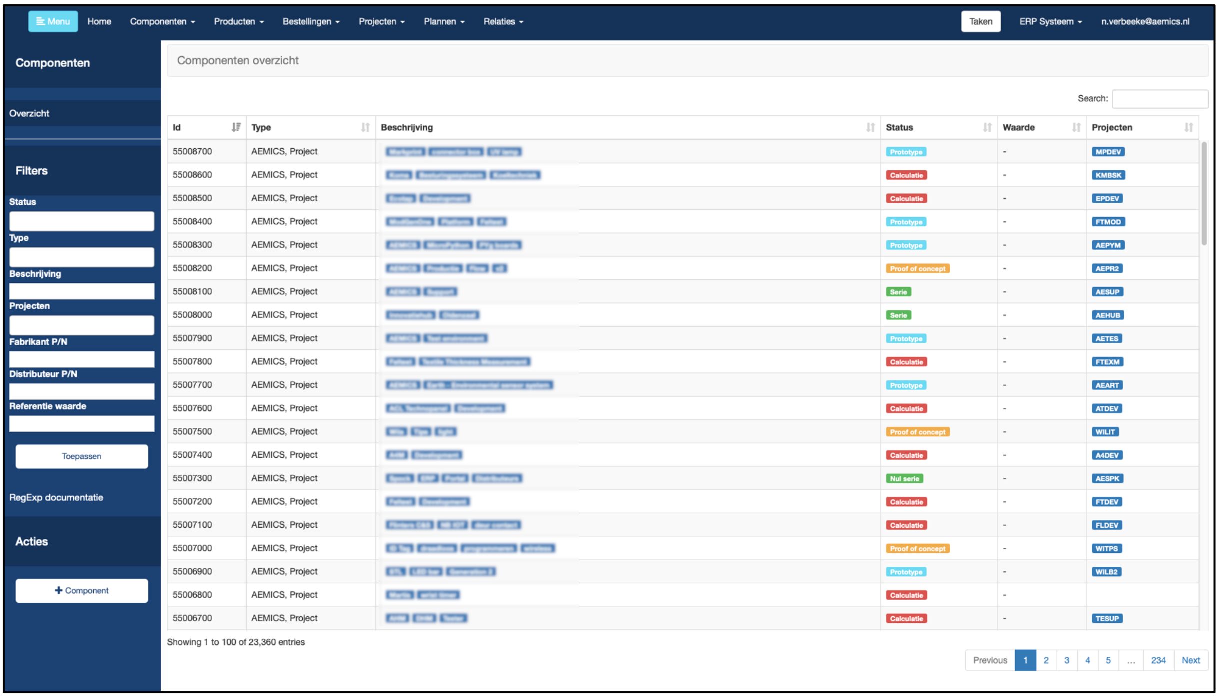
Appendix A. Screenshots ERP system





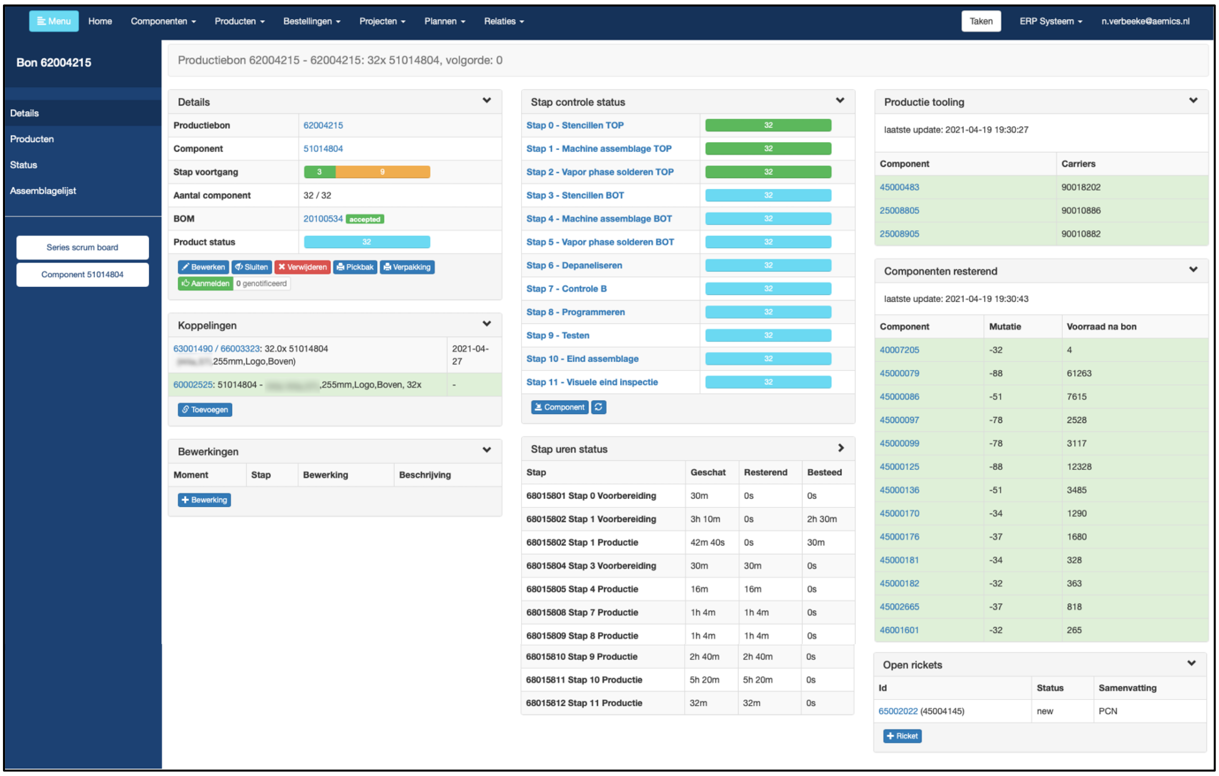
Appendix B. ERP system: Tabs and subtabs

Components *Componenten*	Manage *Beheren*	Table displaying the component Id, type, description, status (*calc, concept, prototype, pilot series, series, obsolete*), value and related projects
	Documents *Documenten*	Table displaying certain documents related to a component
	Rickets *Rickets*	Table displaying rickets made for a component. Rickets are problems with a specific component.
	Reviews *Reviews*	Table displaying review of components
	Changes *Wijzigingen*	Table displaying desired changes for a component
	Component types *Component types*	Table displaying all the types of components
	Manufacturing steps *Producti-estappen*	Table displaying the steps that can be taken with a part.
Products Producten	Manage products *Producten beheren*	Table displaying the product's serial number (S/N), status (completed, discarded, production, RMA), component ID, production sheets, and a description.
	Manage production sheets *Productiebonnen beheren*	Table displaying the production sheet ID, status (done, pending, in progress), quantity, component ID, and a description.
	Manage tools *Gereedschappen beheren*	Table displaying tools.
	Purchase at distributor *Inkopen bij distributeur*	Table displaying orders that are placed.
	Distributor orders	Table displaying orders that are received from distributors.

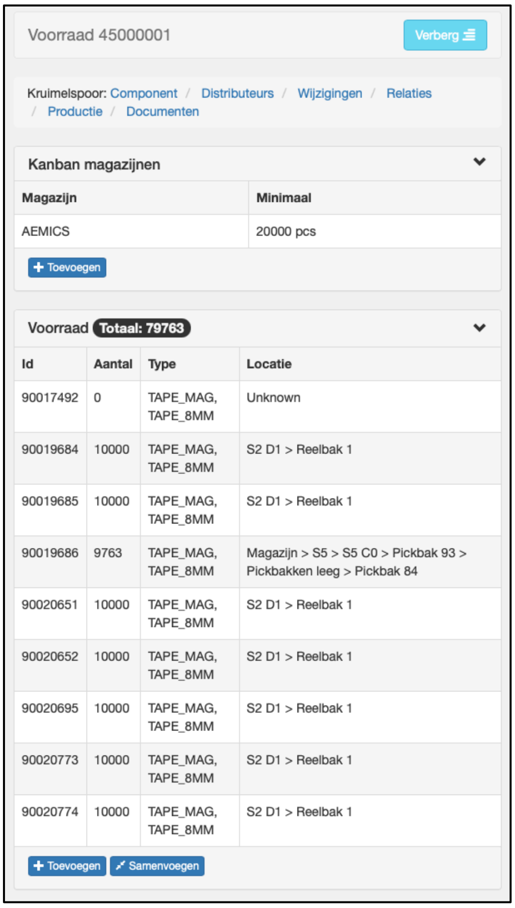
	Distributeur bestellingen	
	Carriers and containers *Carriers en containers*	Table displaying carriers and containers, status, quanity and location
	RMA receipts *RMA bonnen*	Table displaying RMA receipts of products that are returned to AEMICS from a client. A column with the Id, Status, Date when created, Related component, Description, Problem description client
	Transport product *Product transporteren*	Table displaying transports from AEMICS to a client and which transportor.
Orders *Bestellingen*	Manage orders *Bestellingen beheren*	Table displaying the orders that are placed of clients from AEMICS
Projects *Projecten*	Manage projects *Projecten beheren*	Table displaying the projects AEMICS
Planning Plannen	Manage sprints Sprints beheren	Table giving an overview of the sprints
	Prototyping scrum board *Prototyping scrum board*	Scrum board of protoypes
	Series scrum board *Series scrum board*	Scrum board of series
	Support scrum board *Support scrum board*	Scrum board of support activities
	Trainees scrum board *Trainees scrum board*	Scrum board of trainees
	Secondary scrum board *Secondary scrum board*	Scrum board secondary

	Register activities *Werkzaamheden registreren*	Calendar to fill in the issues you worked on
Relations	Manage relations *Relaties beheren*	Table displaying companies related to AEMICS, e.g. clients or distributors and contact phone number
	Manage transporters *Transporteurs beheren*	Table displaying transporters information
	Complaints *Klachten*	Table displaying relations complaint
	Mailing lists *Mailing lijsten*	

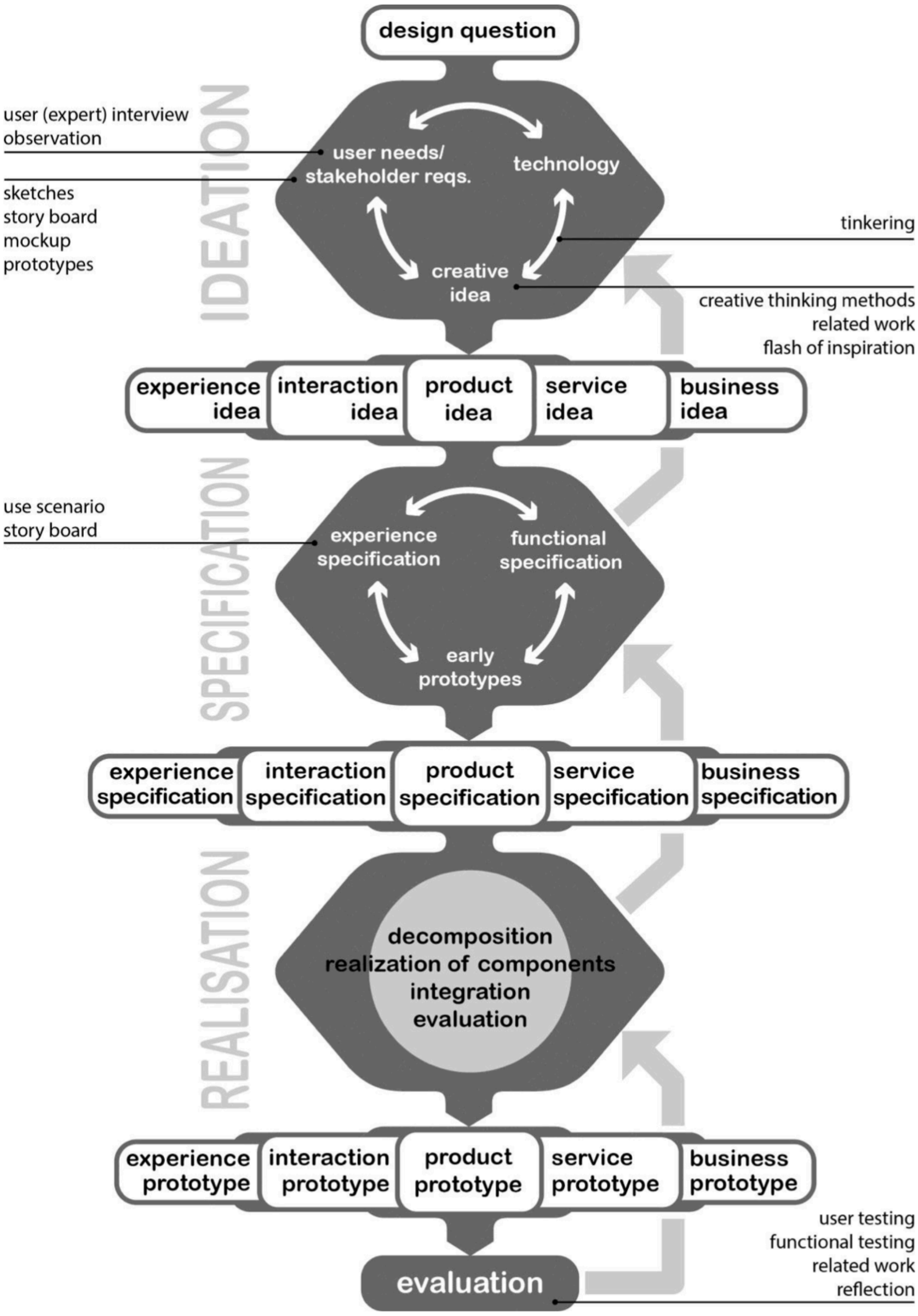
Appendix C. Production process sheet



Appendix D. Sidebar Component



Appendix E. Creative Technology Design Process



Appendix F. Results ‘Empathise’ phase

Pain point	Employee
Dropout / loadloss	
Currently, the drop/load loss is determined by an individual based on the price. *Drop/load loss nu bepaald door persoon op basis van inkoopprijs*	4
It is necessary to load the roles on the feeders several times when feeders are used between projects (resulting in multiple times loss). *Meerdere keren laden van rollen op feeders (=meerdere keren verlies) bij gebruik feeders tussen project*	4
For prototypes, droploss is often not correctly inserted. *Droploss vaak niet goed ingevuld bij prototype*	4
Learning curve P&P (loss) of prototypes *Inleercurve component P&P (verlies) bij prototype*	4
Parameters of components are incorrect *Parameters kloppen niet onder component*	5
When am I allowed to throw away components - when do I retrieve components from the bin? *Wanneer mag ik component weggooien – wanneer moet ik uit bakje vissen?*	5
Delivery – Reel – Tube – Tray significant loss *Aanlevering – Reel – Tube – Tray grote uitval???*	6
Losses that are larger than expected should be noticed sooner. *Uitval hoger dan verwacht eerder constateren*	5
Loss of components is only displayed in MyCenter *Uitval componenten alleen bekend MyCenter*	5

Production data	
The BOM is changed during picking and machine *BOM veranderd tussen picken en machine*	5
Not all components are included in the BOM *Niet alle onderdelen staan in de BOM*	5
Status components inventory – active- obsolete - prototype *Status componenten voorraad – active – obsolete – prototype*	6

Kanban	
When does something move from project based to Kanban?	5

Wanneer gaat iets van project-matig naar Kanban	
General size … Inventory (Boxes – bags) *Algemeen grootte …. Voorraad (- Dozen -Zakken)*	6
Thermal glue based on the size of the production process sheets *Thermische lijm op grootte van productiebon*	6
Unclear which components would be beneficial to have as Kanban. *Onduidelijk wat nuttig is op kanban te hebben*	1
No method to determine Kanban quantities *Geen methode vast stellen kanban hoeveelheden*	2
Ordering Kanban components is too much work *Kanban bestellen is veel werk*	2
Used Kanban stock is collected per component and entered manually *Gebruikte kanban voorraad wordt per component verzameld en handmatig ingevoerd*	3
Currently Kanban is a manual check on the actual stock *Kanban is nu nog een handmatige controle op actuele voorraad*	3
Optimalization Kanban stock versus kanban minimum *Optimalisatie kanban voorraad versus kanban minimum*	3

Mismatch	
Current stock is incorrect *Actuele voorraad klopt niet*	5
Real number does not match with ERP system *Werkelijke aantal matched niet met system*	5
The inventory write-off does not completely correspond to the completed step in the production receipt *Afboek voorraad matched niet goed genoeg met voltooide stap in productiebon*	1
Inventory in system is not correct *Voorraad in systeem klopt niet*	2
Component is incorrect (manufacturer code does not match)	5

Inventory	
Forgetting to write off a carrier *Vergeten af te boeken van carrier*	1
Too many inventory *Te veel voorraad in magazijn*	1
Errors occur when a shipped component is added to stock. *Fout inboeken*	1
No stocktaking *Geen inventarisatie*	2
Wrong stickers *Verkeerde stickers*	2

Miss out *Mis grijpen*	2
When should I write off a carrier at PCB, hand assemblage *Wanneer moet ik carrier afboeken bij PCB, hand assemblage*	5
Miss out / not enough available components *Misgrijpen / is niet genoeg*	7

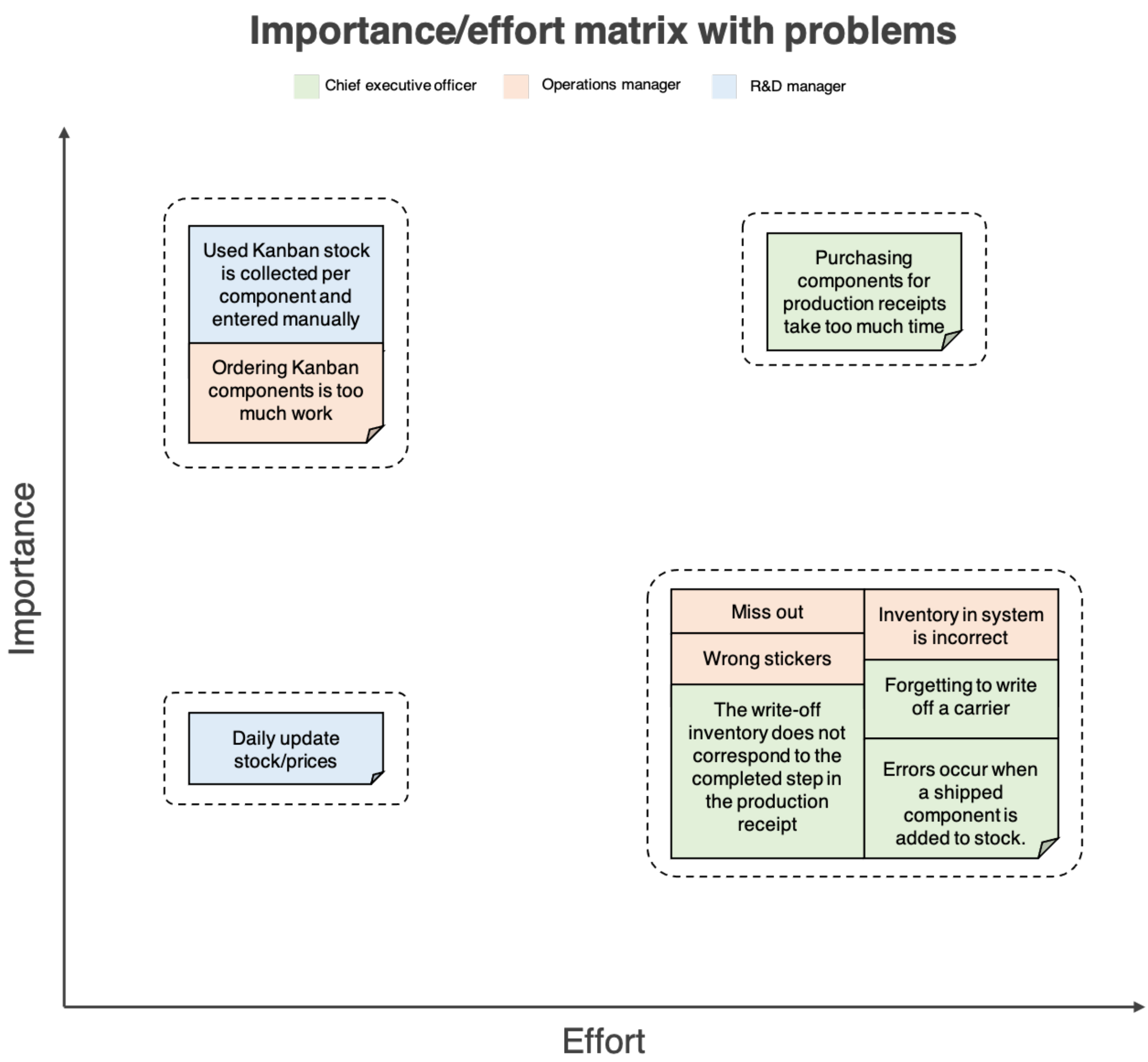
ERP	
Unclear to see the effects of changes in planning *Onduidelijk om gevolgen van schuiven in de planning te zien*	1
The location of the carrier is unknown *Locatie carrier onbekend*	1
Not all displayed prices in ERP are exclusive VAT *Niet alle prijzen in ERP zijn ex btw*	1
Distributor code does not match with paraplu number *Distributeur code klopt niet met paraplu nummer*	2
No financial link ERP – orders – fact *Geen financiele koppeling ERP – orders – fact*	2
There is no check on logical and illogical inventory mutations *Geen check op logische en onlogische voorraad mutaties*	2
Digital check on MFPN (manufacturing part number) *Elektronische controle op MFPN (manufacturing part number)*	3
There is no option to have multiple MFPN associated to 1 component *Mis de optie voor meerdere MFPN onder 1 component*	3
Daily update stock/prices *Dagelijkse update voorraad/prijzen*	3
Remaining components is bad *Componenten resterend is ruk*	5
Fabric lead times at component stock are not committed to production receipt *Fabric lead times bij component voorraad wordt niet gecommit aan productiebon*	3

Procurement	
The supplier is out of stock *Geen voorraad bij leverancier*	1
Purchasing components for production process sheets take too much time *Inkopen kost te veel tijd van productiebon bestellingen*	1
The prices of products at AEMICS are not connected to quotations *AEMICS product prijzen niet gekoppeld aan offertes*	2
Components on strip/cuttape are sometimes purchased even though they are still in stock.	4

Er worden soms componenten op strip / cuttape ingekocht terwijl deze gewoon op rol op voorraad liggen	

Other	
Inexplicable gross margin values *Onverklaarbare bruto marge waarden*	2
The components must be delivered on schedule (week before) *Onderdelen op tijd binnen (week van tevoren)*	5
Shelf life inventory (pasta, flux, etc.) *Houdbaarheid voorraad (pasta, flux, enzo…)*	6

Appendix G. Matrix ‘Empathise’



Appendix H. Results co-creation session I

Category 1 = Purchasing components for production process sheets take too much time
Category 2 = Purchasing Kanban components take too much time
Category 3 = Daily update
Category 4 = Inventory mismatch

Employee A	
Category 1	After refining the shopping list, export to BOM to place an order with the distributor at once *Na inkooplijst optimalisatie export naar BOM om zo bij distributeur in 1x bestelling te plaatsen*
Category 3	Daily: Kanban components and active production process sheets *Dagelijks: Kanban componenten en actieve productiebonnen*

Employee B	
Category 1	Orders may be placed using an API. *Via API bestellingen plaatsen* Automatic booking of order confirmations *Automatisch inboeken order bevestigingen* Procurement dashboard todo mutations *Inkoop dashboard todo afwijkingen* Check the inventory before making an order *Voorraad check voordat je besteld*
Category 2	Per week, calculate Kanban and create a procurement list automatically. *Kanban automatisch elke week uitrekenen + inkooplijst generen*
Category 3	Daily update: open purchase order lines *Dagelijkse update: openstaande inkoopregels*
Category 4	Purchase price per item > calculate the monthly purchasing value *Inkoopprijs per artikel > inkoopwaarde per maand uitrekenen* Inventory forecast vs. Real inventory *Voorraad verwachting vs. Voorraad verloop* Top 10 mutations on each day on quantity / value *Top 10 mutaties per dag op aantal / waarde* Live inventory € daily mutations *Live voorraad € dagelijkse mutaties* Triggers on allogical mutations *Triggers op onlogische mutatie*

Employee C	
Category 1	Optimalization of purchase order lines using the price and inventory at distributor *Optimalisatie inkoop regels op basis van: Prijs, nnvoorraad bij distributeur* Inform the distributor of the expected arrival date *Datum van levering aangeven bij distributeur*
Category 2	Generate procurement list using inventory, expected inventory, delivery time of distributor *Automatische inkooplijst maken op basis van: Voorraad, Verwachte voorraad, levertijd distributeurf*
Category 3	Keep track of “Rate limit” of distributor API and daily use the remainder *“Rate limit” van distributeur API bijhouden en restant elke dag gebruiken* Determine the priority of price update per component *Prioriteit van prijsupdate per component bepalen*
Category 4	Record in which step a component is used *Vastleggen in welke stap een component gebruikt wordt* Connect carrier production step to table. When a step is completed write off carrier. *Koppelen carrier productiestap aan tafel. Bij voltooide stap carrier afboeken.* Create consumption and forecast graph per component. Use deviations between these as a trigger. *Maken verbruik en prognose lijn per component. Afwijkingen hiertussen als alarm gebruiken*

Appendix I. Results co-creation session II

Category 1 = Kanban
Category 2 = Triggers
Category 3 = BOM
Category 4 = Other

Employee D	
Category 1	Every week, recount the used kanban. Trigger on parameter [company name of client] / AEMICS *Verbruikte kanban per week hertellen. Triggeren op parameter [bedrijf van client]/ AEMICS*
Category 1	Determine what should be in kanban and when it should be in kanban *Uitzoeken wat in kanban en wanneer*
Category 2	Check if a component has all of its parameters *Triggeren dat alle parameters onder een component staat*
Category 2	Trigger the loss of components from MyCenter to ERP *Uitval componenten triggeren van MyCenter naar ERP*
Category 3	Let the production team review the BOM before making orders *Controle op een BOM door productie*
Category 4	General inventory (less bins, less locations, overview) *Algemeen magazijn (minder bakken, minder locaties, overzicht)*

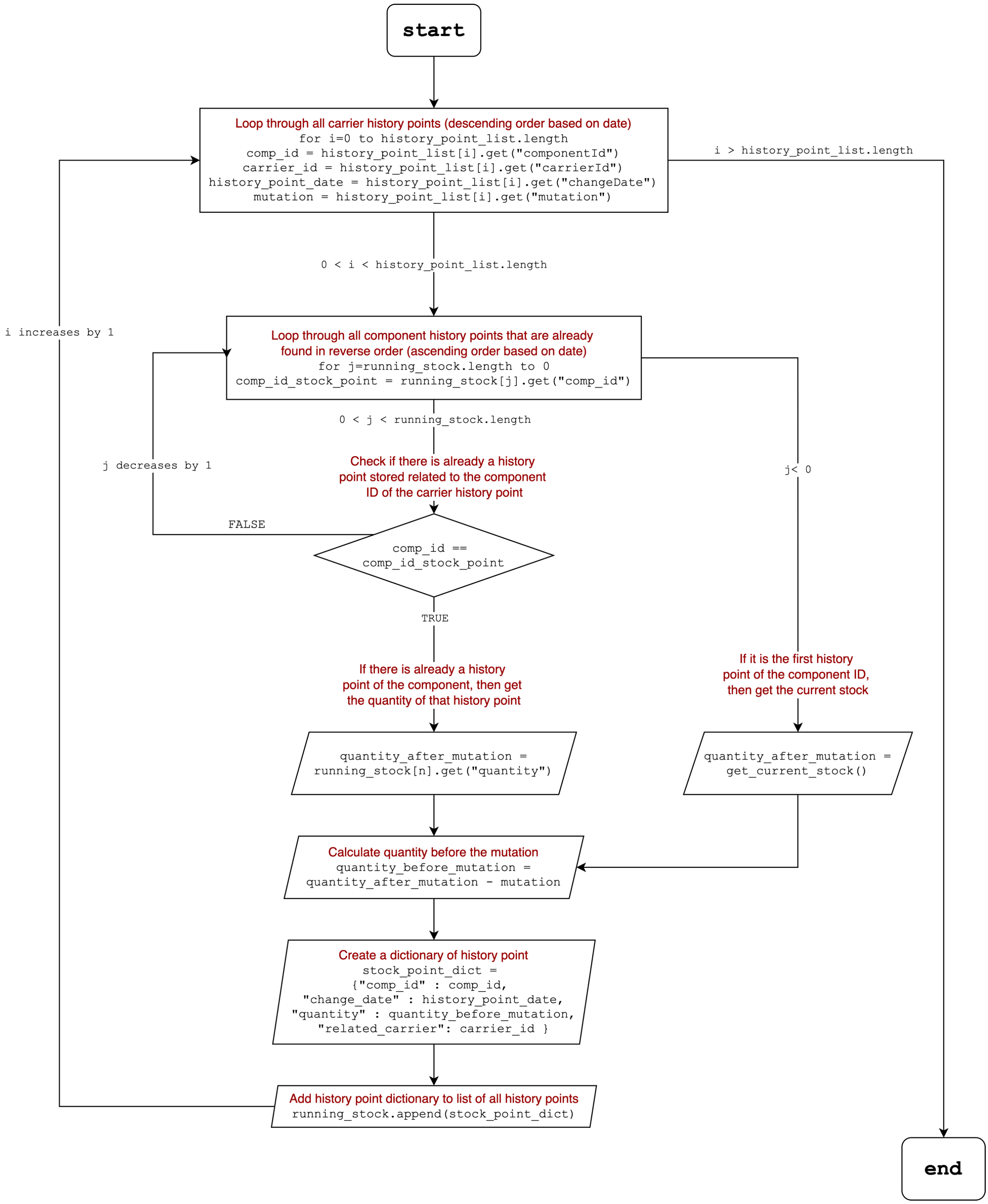
Employee E	
Category 1	Automate weekly kanban procurement *Kanban inkoop automatiseren per week*
Category 2	Write off final project alert notification when closing P.B. because of writing off *Afboeken eindproject alert melding bij sluiten P.B. i.v.m. afboeken*
Category 2	BOM differences alert notification *BOM wijzigingen alert melding*
Category 3	Adapt the BOM to include all elements (incl. packaging), e.g. BOM for packaging. *BOM aanpassen met alle onderdelen (incl. verpakken) bijv. verpakkings BOM*
Category 4	Involve production team in work preparations *Productie betrekken bij werkvoorbereiding*
Category 4	Add expiration date to parameters

	Houdbaarheidsdatum onder parameters toevoegen
Category 4	Percentage of loss calculated using component type (standard) parameters *Uitvalpercentage op basis van component type (standaard) parameters*
Category 4	Procurement should consider the drop/load loss, also with prototypes. *Inkopen rekening houden met drop/load loss ook bij prototypes*
Category 4	Keep track of SMD hand assemblage in hours *SMD handplaatsingen loggen in uren*

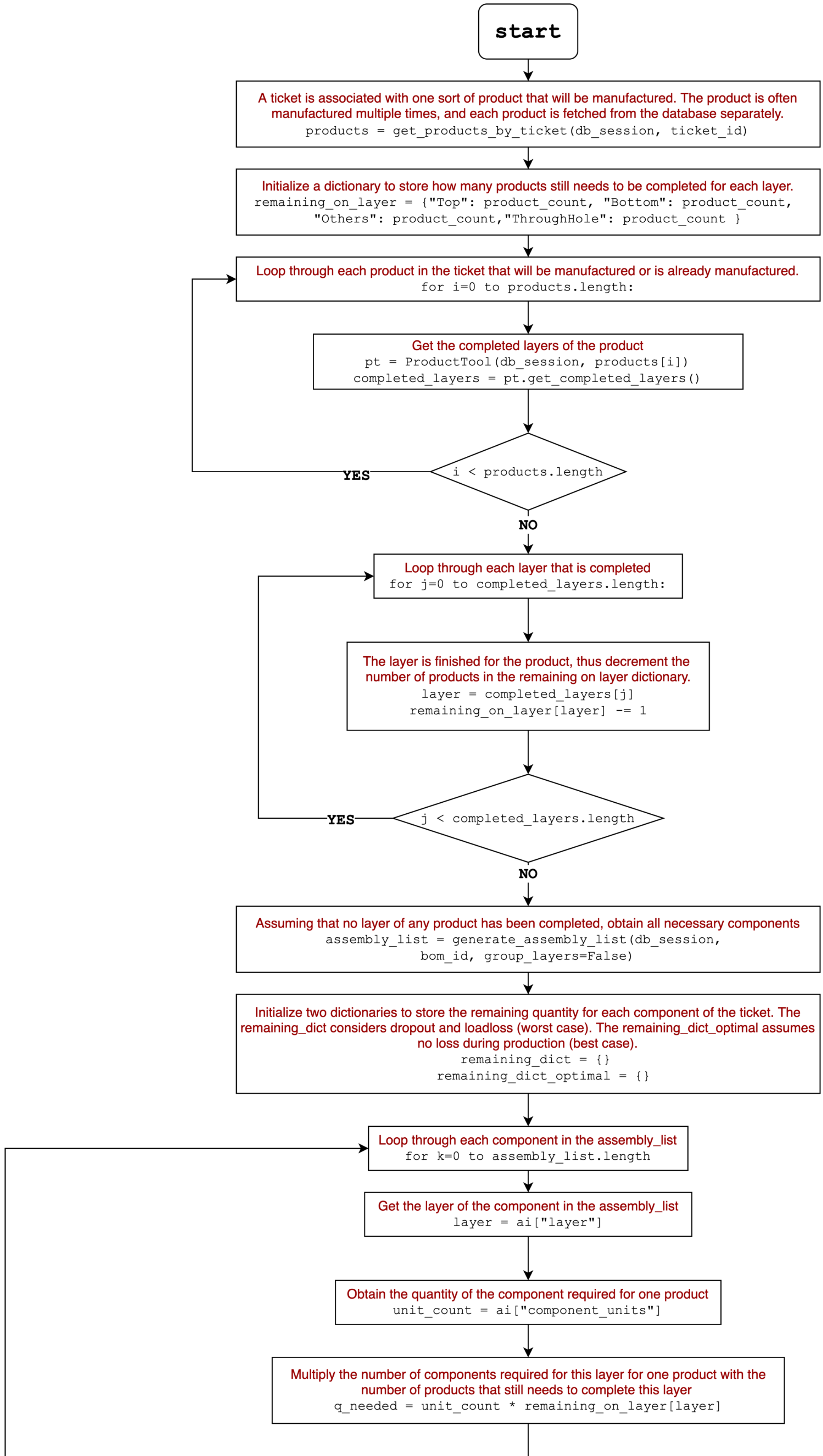
Employee F	
Category 2	BOM should be leading again via trigger *Maak BOM weer leidend door trigger*
Category 2	Determine where the bottlenecks are related to machine loss *Waar liggen pijnpunten uitval machine*
Category 2	Use Mycronic Data to fine-tune the packaging *Data Mycronic gebruiken om packagen te tunen*

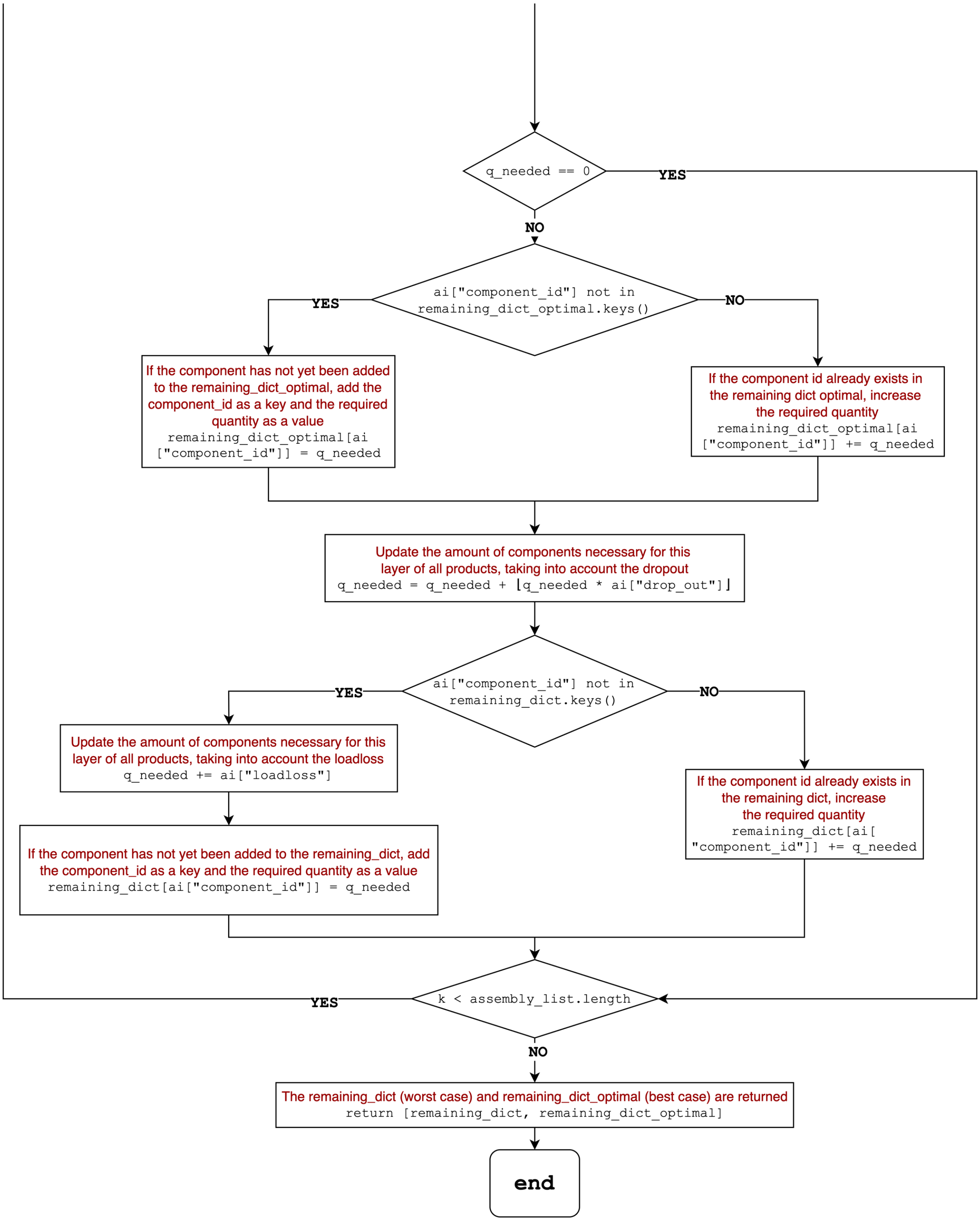
Employee G	
Category 1	Automatically create a list that shows kanban when you discard something *Automatische lijst waar kanban in komt te staan zo gauw je discard*
Category 4	The current stock should be considered during procurement. Alternatively, search the bin first to see if there is any inventory, then place the order. *Bij inkoop goed op voorraad letten. Of eerst bak picken om te zien of de voorraad er ook daadwerkelijk is en daarna inkopen.*
Category 4	Display the component bag / role's remaining value (price) *Restant waarde component zakje/rol weergeven*
Category 4	When a project is finished, throw away the bags containing a small amount of components *Als een project af is met componenten in zakjes lage aantallen discarden.*

Appendix J. Flow chart inventory history



Appendix K. Flow chart remaining





q_needed == 0
YES
NO
ai["component_id"] not in remaining_dict_optimal.keys()
YES
NO
If the component has not yet been added to the remaining_dict_optimal, add the component_id as a key and the required quantity as a value
remaining_dict_optimal[ai ["component_id"]] = q_needed
If the component id already exists in the remaining dict optimal, increase the required quantity
remaining_dict_optimal[ai ["component_id"]] += q_needed
Update the amount of components necessary for this layer of all products, taking into account the dropout
q_needed = q_needed + ⌊q_needed * ai["drop_out"]⌋
ai["component_id"] not in remaining_dict.keys()
YES
NO
Update the amount of components necessary for this layer of all products, taking into account the loadloss
q_needed += ai["loadloss"]
If the component id already exists in the remaining dict, increase the required quantity
remaining_dict[ai["component_id"]] += q_needed
If the component has not yet been added to the remaining_dict, add the component_id as a key and the required quantity as a value
remaining_dict[ai["component_id"]] = q_needed
YES
k < assembly_list.length
NO
The remaining_dict (worst case) and remaining_dict_optimal (best case) are returned
return [remaining_dict, remaining_dict_optimal]
end

Appendix L. Product backlog

Inventory forecast	As a purchaser, I want to be able to examine the expected changes in a component's inventory level in order to determine whether the inven-tory level of a Kanban component falls below the Kanban minimum quantity.
	As a purchaser, I want to be able to see the expected changes in a component's inventory level in order to determine whether the inventory level becomes negative, indicating that I should order the component in order to have enough for production.
Inventory history	As a purchaser, I want to be able to see the history of a component's in-ventory level to determine whether the component's inventory level is on average around the Kanban minimum quantity.
	As a purchaser, I want to be able to view the history of a component's inventory level in order to determine how much the component has been used in the past.
	As an operational manager, I want to be able to view the history of a component's inventory level to determine whether the inventory level was negative, indicating that something went wrong.
Remaining components	As a member of the production team, I want to be able to examine the remaining components of a production process sheet so that I can immediately assess whether there are enough components on hand to complete the production process sheet.
	As a purchaser, I want to be able to review the remaining components of a production process sheet to determine whether components need to be ordered to ensure that the steps in the production process sheet can be completed.
	As an operational manager, I want to be able to see the remaining components of a production process sheet so that I can determine whether to make modifications to the planning.
Current stock	As a member of the production team, I want to be able to see the current inventory level of a component so that I can determine whether there are enough components on hand to manufacture a product.
	As an operational manager, I want to be able to view the current inventory level of component to determine whether the inventory level was negative, indicating that there is a mismatch between reality and the system.
Kanban quantity	As a purchaser, I want to be able to see the current inventory level of a component as well as the minimum Kanban quantity so that I can determine the difference. If the current inventory level is less than the minimum Kanban quantity, the component should be ordered.

Appendix M. Questionnaire user testing

		Adapted from
Function at AEMICS (measured with a checkbox question)	I1: I work at AEMICS as a … Answer options: Production worker; Developer, CEO/Executive assistant; Purchaser; Intern; Other:…. *I1: Ik werk bij AEMICS als ...* *Antwoordopties: Productiemedewerker; Ontwikkelaar; CEO/executive assistant; Inkoper; Stagair; Anders:…*	-
Use frequency (measured with a radiobutton question)	How often do you currently use the inventory analyzer? Answer options: Daily; At least once a week, but not daily; At least once a month, but not weekly; Less than once a month; Rarely or never *Hoe vaak maakt u momenteel gebruik van de inventory analyzer?* *Antwoordopties: Dagelijks; Minstens 1 keer per week, maar niet dagelijks; Minstens 1 keer per maand, maar niet wekelijks; Minder dan 1 keer per maand; Zelden of nooit* [If the answer to this question is "Rarely or never" then questions in the block "Performance Expectancy Individual" and are not asked to the participant]	-
Use of the inventory analyzer* (measured with open questions**)**	What is the reason that you use the inventory analyzer? *Wat is de reden dat u gebruik maakt van de inventory analyzer?* Please tell me more about your most recent use of the inventory analyzer. Do you recall what triggered you to look at the inventory visualizations? Were you able to find what you were looking for? *Vertel me meer over de meest recente keer dat u gebruik heeft gemaakt van de grafiek(en) van de inventory analyzer. Weet u nog wat u ertoe bracht om naar de grafiek(en) te kijken? Heeft u kunnen vinden wat u zocht?*	-
Performance Expectancy Individual* (measured	**PI1:** I think the inventory analyzer is useful in my job. *Ik vind de inventory analyzer nuttig in mijn werk.*	[65]

with 5-point Likert- scale)	**PI2:** The visualization of the inventory analyzer fully support my work tasks. *De grafieken van de inventory analyzer ondersteunen mijn werktaken volledig.*	[50]
	PI3: The inventory analyzer enables me to use inventory data in a smarter way. *De inventory analyzer zorgt ervoor dat ik slimmer gebruik kan maken van inventory data.*	[50]
	PI4: The charts of the inventory analyzer allow me to make more intelligent business decisions. *De grafieken van de inventory analyzer zorgen ervoor dat ik intelligentere business beslissingen kan maken.*	[50]
	PI5: I can clearly see how the inventory analyzer would enable me to increase my productivity. *Ik kan duidelijk zien hoe de inventory analyzer mijn productiviteit kan verbeteren.*	[65]
	PI6: Using the inventory analyzer enables me to accomplish my tasks more quickly. *Het gebruiken van de inventory analyzer zorgt ervoor dat ik mijn taken sneller af heb.*	[65]
Performance Expectancy General (measured with 5-point Likert- scale)	**PG1:** The inventory analyzer enables AEMICS to use inventory data in a smarter way. *De inventory analyzer zorgt ervoor dat AEMICS inventory data op een slimmere manier kan gebruiken.*	[50]
	PG2: I have a clear understanding of how the inventory analyzer adds value to AEMICS *Ik kan goed begrijpen hoe de inventory analyzer waarde toevoegt bij AEMICS.*	[50]
	PG3: The functions of the inventory analyzer allow AEMICS to make more intelligent business decisions. *De functies van de inventory analyzer zorgen ervoor dat AEMICS intelligentere business beslissingen kan maken.*	[50]
Performance Expectancy Procurement (measured	**PP1:** The inventory analyzer brings valuable insights for procurement of components. *De inventory analyzer zorgt voor waardevolle inzichten bij de inkoop van componenten.*	[50]

with 5-point Likert- scale)		
	PP2: The inventory analyzer has a positive impact on the work performance of the purchasers. *De inventory analyzer heeft een positieve impact op de werkprestaties van de inkopers.*	[50]
	PP3: I can clearly see how the inventory analyzer enables purchasers to increase their productivity. *Ik kan duidelijk zien hoe de inventory analyzer de productiviteit van de inkopers kan verbeteren.*	[65]
	PP4: The functions of the inventory analyzer allow purchasers to make more intelligent business decisions. *De functies van de inventory analyzer zorgen ervoor dat de inkopers intelligentere beslissingen kunnen maken.*	[50]
	PP5: Using the inventory analyzer enables purchasers to accomplish their tasks more quickly *Het gebruiken van de inventory analyzer zorgt ervoor dat de inkopers hun taken sneller af hebben.*	[65]
Performance Expectancy Production Team (measured with 5-point Likert- scale)	**PE1:** The inventory analyzer brings valuable insights for production team. *De inventory analyzer zorgt voor waardevolle inzichten bij het productieteam.*	[50]
	PE2: The inventory analyzer has a positive impact on the work performance of the production team. *De inventory analyzer heeft een positieve impact op de werkprestaties van het productieteam.*	[50]
	PE3: I can clearly see how the inventory analyzer would enable production team to increase their productivity. *Ik kan duidelijk zien hoe de inventory analyzer de productiviteit van het productieteam kan verbeteren.*	[65]
	PE4: The functions of the inventory analyzer allow production team to make more intelligent business decisions. *De functies van de inventory analyzer zorgen ervoor dat het productieteam intelligentere beslissingen kan maken.*	[50]
Effort Expectancy (measured with 5-point Likert- scale)	**EE1:** The inventory analyzer is easy to use. *De inventory analyzer is makkelijk te gebruiken.*	[65] [52]
	EE2: It is quickly apparent how to use the tooltips. *Het is meteen duidelijk hoe je gebruik kunt maken van de tooltips.*	[52]
	EE3: It is quickly apparent how to hide a line in the graph. *Het is meteen duidelijk hoe je een lijn kan verbergen in de grafiek.*	[52]
	EE4: Understanding the charts is easy for me.	[50]

	Ik vind de grafieken makkelijk te begrijpen.	
	EE5: Generating insights from the charts is easy for me. *Het is makkelijk om inzichten uit de grafieken te halen.*	[50]
Behavioural Intention to Use the system (measured with a Yes/No question)	**B1:** I expect to use the inventory analyzer in the approaching month. *Ik verwacht de inventory analyzer te gebruiken in de aankomende maand.*	[65]
Visual aesthetics (measured with 5-point Likert- scale)	**V1:** I recognize the elements of creative design in the inventory analyzer. *Ik herken de elementen van een creatief ontwerp in de inventory analyzer.*	[52]
	V2: The design of the charts looks attractive. *Het design van de grafieken is aantrekkelijk.*	[52]
	V3: Compared to other software products in the company, the inventory analyzer stands out for its design. *In vergelijking met andere softwareproducten in het bedrijf, springt de inventory analyzer eruit qua design.*	[52]
	V4: The charts of the inventory analyser are stylish. *De grafieken van de inventory analyzer zijn stijlvol.*	[52]
Remarks (measured with open questions)	**R1:** What could be done to improve the inventory analyzer? Was there anything missing from the inventory analyzer that you expected? *Wat kan er worden gedaan om de inventory analyzer te verbeteren? Ontbreekt er iets aan de inventory analyzer dat u had verwacht?*	-
	R2: Does the inventory analyzer so far provide all the information you need related to inventory? If not, what is missing? *Toont de inventory analyzer tot nu toe alle informatie met betrekking tot voorraad? Zo niet, wat ontbreekt er?*	-
Components remaining (measured with a Yes/No question)	**CR1:** Did you ever look at the "Remaining components" table in ERP? *Heeft u ooit gekeken naar de "Componenten resterend" tabel in ERP?*	-
Performance Expectancy Components remaining table** (measured	**CE1:** I think the components remaining table is useful in my job. *Ik vind de componenten resterend tabel nuttig in mijn werk.*	[65]

with 5-point Likert- scale)	**CE2:** The components remaining table enables me to use inventory data in a smarter way. *De componenten resterend tabel zorgt ervoor dat ik slimmer gebruik kan maken van inventory data.*	[50]
	CE3: The components remaining table allow me to make more intelligent business decisions. *De componenten resterend tabel zorgt ervoor dat ik intelligentere business beslissingen kan maken.*	[50]
	CE4: I can clearly see how the components remaining table would enable me to increase my productivity. *Ik kan duidelijk zien hoe de componenten resterend tabel mijn productiviteit kan verbeteren.*	[65]
	CE5: Using the components remaining table enables me to accomplish my tasks more quickly *Het gebruiken van de componenten resterend tabel zorgt ervoor dat ik mijn taken sneller af heb.*	[65]
Remarks remaining components table** (measured with an open question)	**RC1:** What could be done to improve the remaining components table? Was there anything missing from the remaining components table that you expected? *Wat kan er worden gedaan om de componenten resterend tabel te verbeteren? Ontbreekt er iets aan de componenten resterend tabel dat u had verwacht?*	-

* This section appears only if the respondent has indicated to use the inventory analyzer.

** This section appears only if the respondent has indicated to use the remaining components table.

Appendix N. Interview questions

	Adapted from
Position within AEMICS	
▪ What is your position within AEMICS? *Wat is uw functie binnen AEMICS?*	-
Goals	
▪ What are the top goals and priorities in your role? *Wat zijn de top goals (doelen) en prioriteiten binnen uw functie?*	[64]
▪ What mistakes or missed opportunities can be prevented if you have data? *Welke fouten of gemiste kansen kunnen worden voorkomen als u de juiste data beschikbaar hebt?*	[64]
▪ What information do you need on a daily basis? *Welke informatie (data) heeft u dagelijks nodig?*	[64]
▪ Which decisions do you make based on this data? *Welke beslissingen maakt u op basis van deze data?*	[64]
▪ How does the inventory analyzer assist you in making decisions? Could you give an example? *Hoe ondersteunen de grafieken van de inventory analyzer u in het maken van deze beslissingen? Kan je hier een voorbeeld van geven?*	-
▪ What impact does the inventory analyzer currently have on your work? *Welke impact heeft de inventory analyzer moment op uw werk?*	-
Context of use	
▪ What triggers you to look at the visualizations of the inventory analyzer?	[64]

Wat triggert u om te kijken naar de grafieken van de inventory analyzer van een bepaald component?	
▪ How much time do you usually spend looking at the visualizations of a component? *Hoeveel tijd besteedt u gemiddeld aan het kijken naar de visualisaties van één bepaald component?*	[64]
▪ What data will prompt you to immediate action if you see it? *Welke data uit de grafieken zou er voor zorgen dat u meteen ingrijpt?*	[64]

User experience	
▪ What's most appealing about the inventory analyzer? *Welk onderdeel van de inventory analyzer spreekt u het meest aan?*	[63]
▪ What did you like the least? *Welk onderdeel van de inventory analyzer spreekt u het minst aan?*	[63]
▪ Was there anything surprising or unexpected about the inventory analyzer? *Is er iets verrassend of onverwachts aan de inventory analyzer? Zo ja, wat?*	[63]
▪ What, if anything, caused you frustration? *Was er iets dat irritatie veroorzaakte bij het gebruik van de inventory analyzer?*	-
▪ Was there anything missing from the inventory analyzer that you expected? *Is er iets dat nog mist aan de inventory analyzer wat u had verwacht? Zo ja, wat?*	[63]
▪ Generally speaking, do figures seem correct to you? If not, please list the potential errors you have spotted. *Over het algemeen genomen, zien de grafieken er correct uit in uw perspectief? Zo niet, wat zijn potentiele fouten die u heeft gezien?*	-

Appendix O. Results questionnaire: remaining components table

Did you ever look at the "Remaining components" table in ERP?

RESPONSE	COUNT	PERCENT
Yes	4	30,77%
No	0	0,00%
Not shown	9	69,23%

I think the components remaining table is useful in my job.

RESPONSE	COUNT	PERCENT
Strongly disagree	1	7,69%
Disagree	0	0,00%
Neither agree nor disagree	0	0,00%
Agree	2	15,38%
Strongly agree	1	7,69%
Not shown	9	69,23%

The components remaining table enables me to use inventory data in a smarter way.

RESPONSE	COUNT	PERCENT
Strongly disagree	1	7,69%
Disagree	0	0,00%
Neither agree nor disagree	0	0,00%
Agree	2	15,38%
Strongly agree	1	7,69%
Not shown	9	69,23%

The components remaining table allow me to make more intelligent business decisions.

RESPONSE	COUNT	PERCENT
Strongly disagree	1	7,69%
Disagree	0	0,00%
Neither agree nor disagree	1	7,69%
Agree	2	15,38%

Strongly agree	0	0,00%
Not shown	9	69,23%

I can clearly see how the components remaining table would enable me to increase my productivity.

RESPONSE	COUNT	PERCENT
Strongly disagree	1	7,69%
Disagree	0	0,00%
Neither agree nor disagree	2	15,38%
Agree	1	7,69%
Strongly agree	0	0,00%
Not shown	9	69,23%

Using the components remaining table enables me to accomplish my tasks more quickly

RESPONSE	COUNT	PERCENT
Strongly disagree	1	7,69%
Disagree	0	0,00%
Neither agree nor disagree	1	7,69%
Agree	2	15,38%
Strongly agree	0	0,00%
Not shown	9	69,23%

What could be done to improve the remaining components table? Was there anything missing from the remaining components table that you expected?

ORIGINAL RESPONSE	TRANSLATION
Op het moment dat er niet voldoende voorraad is van een component deze graag in rood (nu groen) weergeven	When there is insufficient stock of a component, highlight it in red (currently green)
Load loss parameters zorgen voor onduidelijkheid	Load loss parameters cause misunderstandings