Guiding Voortman customers to optimize machine output

By

Thijs Rolleman (s2775778)

Supervisors

University of Twente: dr. ir. E.J. Faber & dr. L. Gatti

Voortman Steel Machinery: J. Wanink (Functional Analyst) & H. Nijzink (Product Owner)

Graduation Project BSc Creative Technology

Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS)

University of Twente

14 July 2024

Abstract

In the industry of steel manufacturing, optimizing machine output is important for maintaining efficient production and reducing production costs. This thesis, titled "Guiding Voortman customers to optimize machine output," addresses the issue at Voortman Steel Machinery of guiding the customers' production managers in the process of machine optimization by providing actionable feedback, which leads into the main research question:

How can actionable feedback be provided for production managers to optimize the machine output in an ICT-based tool, to be integrated in EVI?

Through background research, State-of-the-art and interviews with experts, it became clear that maintenance management has a significant contribution to the machine uptime.

To tackle this challenge, a prescriptive maintenance dashboard was designed, aimed at providing production managers with actionable feedback to optimize machine performance. The dashboard integrates real-time data to track the Remaining Useful Life of tools, enabling timely and preventive maintenance actions.

Key features of the dashboard include real-time notifications, indicating when a tool replacement is necessary and suggestions for the specific tools required for upcoming production planning. This predictive approach allows production managers to plan maintenance activities more effectively, and thus minimizing unexpected breakdowns and ensuring efficient production.

The dashboard was more focused on the presentation of the data, rather than the technical aspect of how to acquire that data, ensuring that the interface is intuitive and provides clear visualizations of tool status, RUL predictions, and maintenance recommendations. In addition, by allowing communication between the production manager and the operator, maintenance can be managed more efficiently, leading to an increase in the uptime.

The effectiveness and ease of use of the prescriptive maintenance dashboard was evaluated through user-testing, where experts from Voortman and an external production manager tested the dashboard, and by conducting an interview and a technology acceptance questionnaire afterwards.

This thesis also discusses the challenges faced during the development and implementation of the dashboard, such as data availability issues, the complexity of real-time data

processing, and the many factors that have influence on the machine output. Solutions to these challenges are presented, along with recommendations for future steps in this project.

In conclusion, the prescriptive maintenance dashboard, offering real-time RUL predictions and actionable feedback, substantially improves maintenance management in the steel manufacturing industry. This innovation supports production managers in making informed decisions and communicate these with the operators, leading to optimized machine output, reduced downtime, and increased operational efficiency.

Acknowledgement

I would like to acknowledge everyone who has supported and guided me throughout the process of completing this project. First, my thanks goes to dr. ir. E.J. Faber & dr. L. Gatti, whose supervision, useful advice, and encouragement contributed to the completion of this project. It was a pleasure working with you.

I am also grateful to Voortman Steel Machinery, for providing the necessary resources, support and expertise. Special thanks to J. Wanink (Functional Analyst) & H. Nijzink (Product Owner) for their assistance and support in guiding and supervising me in this project. I appreciated the opportunity to work with you.

Lastly, I am grateful to all the participants and respondents who took the time for interviews which contributed to this project significantly. Without your cooperation, this research would not have been possible.

Thank you all for your support and encouragement. This accomplishment would not have been possible without you.

Thijs Rolleman

Table of Contents

List of Figures

List of Tables

Chapter 1 - Introduction

This chapter initiates the research in this graduation project. First, a brief introduction to Voortman Steel Machinery (VSM) will be given in section 1.1. In section 1.2, the relevance of the assignment is explained, followed by the problem statement and research questions in section 1.3. In section 1.4, the general outline of the report will be provided.

1.1 Voortman Steel Machinery (VSM)

Voortman Steel Machinery is a leading, international company in steel processing and automation. They specialize in designing and building high-end CNC steel processing machines with integrated software solutions, which automate and optimize the manufacturing process. What makes VSM unique is that they can deliver the whole package, unlike other companies. This means that when a company buys a machine at VSM, they not only buy the machine, but also the internally designed software dedicated to Voortman machines, and the service and maintenance the machine needs. The machines and software Voortman provides can be divided into the following categories:

- **Plate Processing Machines**: These machines are designed for processing steel plates with cutting, drilling, marking, and milling capabilities. They can handle plates of various thicknesses and sizes, allowing for efficient fabrication processes.
- **Beam Processing Machines**: These machines are designed to process steel beams by drilling, sawing, coping, or marking them. These machines are crucial in structural steel fabrication, such as construction projects.
- **Robotic Welding Systems (Fabricator)**: Voortman provides robotic welding systems that automate the welding process. This increases the efficiency, as this robot theoretically can work 24/7 and doesn't need breaks. Furthermore, these robots can weld more precisely than humans, producing higher-quality products.
- **Flat & Angle Processing Machines:** These machines are used for processing flat bars, angles, and channels by drilling, punching, and shearing. These parts are essential for fabricating components used in several industries, for example, construction and infrastructure.
- **Pipe Processing Machines**: At the beginning of 2023, VSM took over the German company Müller Opladen, which specializes in CNC-controlled 3D pipe-cutting machines. These pipes can be used in gas stations or oil decks at sea for example.

- **Software Solutions**: In addition to hardware, Voortman provides software solutions specially made for specific machines. This includes CAD/CAM software for designing and programming machine operations, as well as EVI (Extended Voortman Insights) to gain more insights into live machine data and in the future to optimize the output of the machines using this data. This application will be further explained in the section below, as it is important for optimizing the machine output [1]. This all is mostly done by DIGI-Steel, a member of Voortman Steel Group which is focused on the processes around the machines.

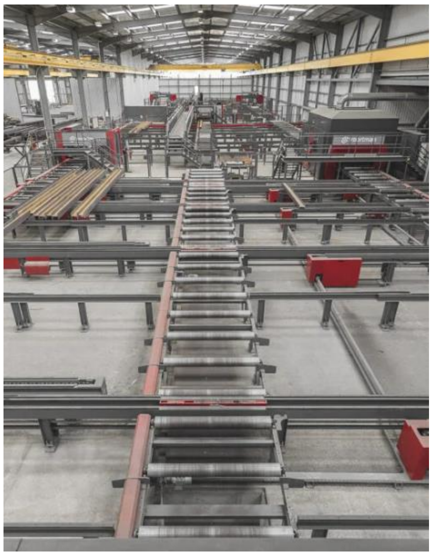


Figure 1.2 Automated production line

- **Fully-automated machine lines:** VSM also offers a fully automated integrated production line with the help of MSI (Multi System Integration). This system connects different machines with cross transports, roller conveyors, product buffers, and material sensors. These machines work together based on the data the user puts in at the beginning of a production process. MSI distributes this data over the machines, and everything will go automatically. This results in a production line where all the machines will process the steel parts after each other automatically, in the right order (figure 2).

1.2 Relevance

DIGI-Steel [2] is a member of the Voortman Steel Group, one of the market leaders for steel machinery. With DIGI-Steel, Voortman introduce the first fully cloud-based software solution for steel processors. It is the next-generation steel workshop management software guiding our customers' factories into the Industry 4.0 era.

The goal of Voortman/DIGI-Steel is to develop software solutions that can easily be used in a factory. Customers are striving to be as efficient as possible. Time is money. Therefore, they want to guide their customers in improving the production output of their machines/machine lines. This is a multidisciplinary topic covering processes, information, and human interaction.

EVI, as part of the Smart Industry topics of Voortman, is one of the first steps in this direction. It is an application tool that helps customers on multiple levels to improve their production efficiency and machine optimization, by providing live insights into the machine status and output in a clear dashboard. This dashboard is mostly looked at by the production manager, as his goal is to get insights into the machine output and to optimize the manufacturing process as much as possible. Getting insights is the first step to improvement. Even though these insights are already very valuable, it can still be hard to identify how to improve the output of a machine.

1.3 Problem Statement & Research Questions

The problem statement of this assignment is that there is no feature yet that takes action or provides information on what to do based on the analysis of the data EVI provides, or that there are certain steps that can be followed to improve the machine performance, which is the goal for manufacturing companies, as time equals money. They want to increase the machine's uptime as much as possible because when the machine is not running, it only costs them money [3]. The uptime of a machine is the time that the machine is running and producing.

The problem is that it can still be hard to identify how to improve this. That is the reason why they want to assist the production managers in this process by providing actionable feedback that can increase the output of the machines. The output of the machine is anything that can be measured from the machine, which says something about the performance.

This involves understanding factory use cases, researching methods such as interviews and literature research, exploring relevant technologies, and finally creating an ICT-based design/prototype, that provides actionable feedback to the customer. Based on this problem, a main research question is set up:

How can actionable feedback be provided for production managers to optimize the machine output in an ICT-based tool, to be integrated in EVI?

As this question is still broad, 3 sub-research questions were set up to specify it more. First, the term 'machine output' has to be defined; as what it is, how it is measured in EVI and what measurement factor gives the best picture of the performance of a machine. This leads to the first sub-question:

What is machine output, and what factors measured in EVI gives the most accurate picture of it?

To find an answer to this question, EVI should be used to see the different machines with their corresponding real-time uptime and output, defined in categories. Furthermore, interviews with experts and literature research should be conducted to gain more perspectives and information on what output is and what factor gives the best view on it.

Secondly, the factor that gives the best indication of how a machine performs should be analysed on how to increase or optimize it, which is the amount of operations in a period of time. This can be done by looking at the elements that influences the amount of operations, which raises the second sub-question:

Which factors determine the amount of operations, and which factor has the most influence on it?

This question can be answered by conducting interviews with production managers and operators, who are familiar with the different factors there are which influence the machine output. After that, the factors should be analysed to see what influence that factor has. Literature research should also be conducted on variables that have an impact on the machine output.

Thirdly, the factor of SRQ2 should be researched to see how it can be improved from the production managers perspective, which will be done in sub-question 3:

How can the factor of SRQ2 be improved by the production manager?

This includes conducting interviews with production managers and other people that have expertise in this topic. Furthermore, literature research should be conducted.

At last, the solution to increase the factor should be translated into actionable feedback, which fits in the environment and needs of the production manager to optimize the machine performance, leading to the last sub-question:

How can this solution be translated into actionable feedback, and displayed to the production manager?

This can be answered by interviewing production managers on what their needs and requirements are, and by conducting literature research on how to show this data to users in the right way.

To have a clear overview of this process, a

roadmap has been made which can be seen in figure 2. This roadmap will be filled in along the process.

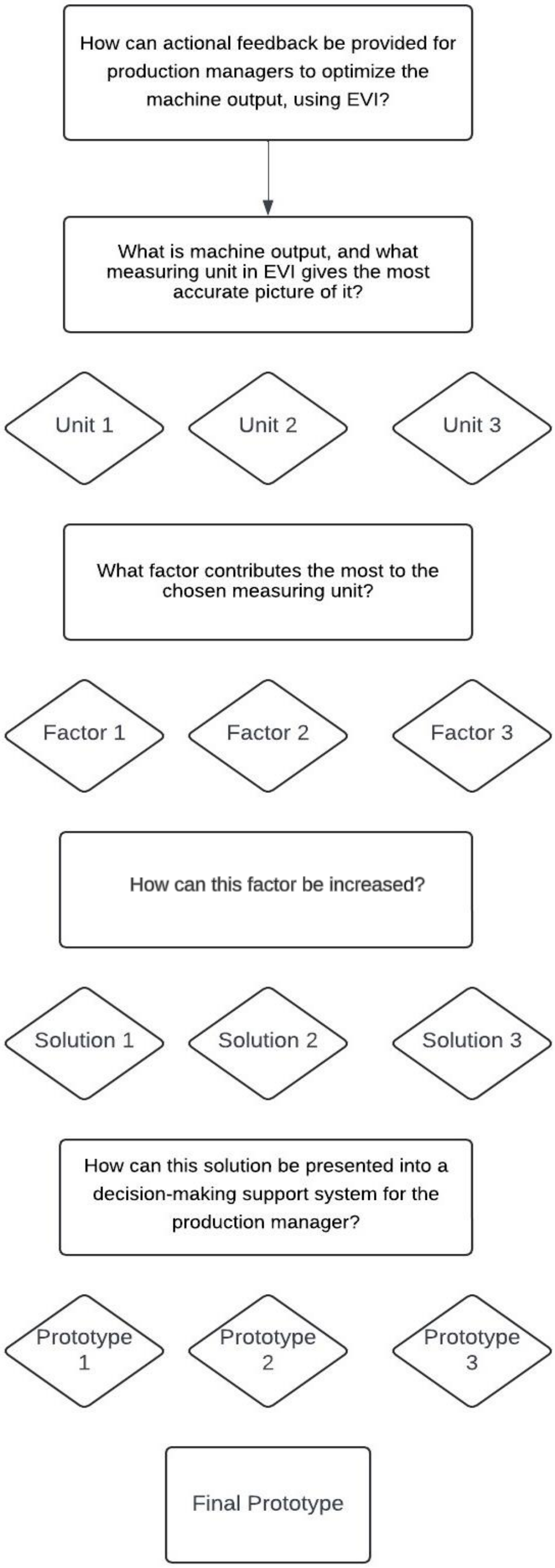


Figure 1.3 GP roadmap

1.4 General Outline

This part will explain what the general report outline will look like. In Chapter 2, deeper background research is conducted into the company and EVI. Furthermore, literature research is executed and the state-of-the-art has been created. In Chapter 3, the methods and techniques used in this study will be explained. In Chapter 4, the ideation phase starts, where possible solutions to the problem are specified. Coming to Chapter 5, one potential solution will be chosen and worked out in detail, followed by the realization of this concept in Chapter 6. In Chapter 7, an evaluation will be done of the research and the prototype to look back on how it went. Chapter 8 is dedicated to the discussion and future work on this project, and continues with the conclusion in chapter 9.

Chapter 2 - Background Research

In this chapter, the company will be introduced as well as the application EVI, to give more context information. Furthermore, the state-of-the-art will be conducted, to get inspiration from other companies and existing products, and to ensure that the wheel won't be invented again.

2.1 Voortman Steel Machinery

Voortman Steel Machinery (VSM) is a family company founded in 1970 in Rijssen, the Netherlands. It started with creating steel structures and automated steel processing machines.

In 1980, two separate companies were established, Voortman Automatisering (automation) and Voortman Steel Construction (VSC). Voortman Automatisering, now known as Voortman Steel Machinery, works on optimizing and automatizing steel processes. Voortman Steel Construction produces structural steel, to create buildings for example.

In 1992, Voortman went already abroad by founding Voortman Deutschland GmbH, to provide better service to the mechanical engineering customers in Germany. Currently, Germany is still an important location for sales and some machines that were installed back then are still running.

In 2004, VACAM was introduced, which made a great change in the software development of their steel processing machines. VACAM is an intern-designed software that runs on the Voortman machines, providing the user maximum control and flexibility, and is still updated to this day [4].

In 2014, Voortman introduced the state-of-the-art Experience Center (VEC). In this center, the different machines are showcased and potential clients or people who are interested can see here how the machine operates and what they are capable of. Furthermore, training facilities are implemented to teach employees and clients how to operate the machines.

Figure 2.1 Voortman Experience Center

In 2023, VSC was sold to Severfield, a leading structural steel company in the United Kingdom. Furthermore, VSM acquired the German company Müller Opladen, which specializes in CNC-controlled 3D pipe-cutting machines. These pipes can be used in gas stations or oil decks at sea for example [5].

During these decades, VSM kept growing and more offices were built abroad to provide a worldwide service and to reach customers from all over the world. Currently, VSM has grown into a leading professional in creating high-end CNC steel processing machines with integrated business software that automates and optimizes steel production, and around 600 employees. An overview can be seen in Table 1 [6].

Country	City	Address
Netherlands	Rijssen	Ozonstraat 1 (Headquarters)
United States	Monee	26200 S Whiting Way
Australia	Cleveland	Grant Street Business Centre
France	Nantes	22 Mail Pablo Picasso
Germany	Gronau (Westfalen)	Gildehauser Str. 2
Poland	Kraków	Smoleńsk 18/1
Russian Federation	Sankt-Peterburg	Ulitsa Reshetnikova, 17, building 1a, Sankt-Peterburg
United Kingdom	Stockport	Unit 7 S: Park Business Park Martel Court, Hamilton Rd

Table 2.1 Locations of Voortman Steel Group

2.2 EVI (Extended Voortman Insights)

2.2.1 Meet EVI

EVI is a software application in development running on a hardware device (figure 2.2) that can be attached to any Voortman machine. The user can assess this application through the EVI app on a mobile phone or tablet, and the webpage on a laptop. EVI is already used on machines at Voortman and other companies to pilot test it, as it is still in the development phase. The goal is to release the EVI application on the 1st of April.

Figure 2.2 EVI Hardware device

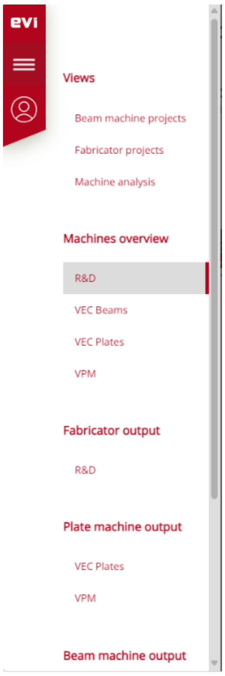


Figure 2.3. Selection menu

There are several advantages of EVI. First, when using EVI, live insights and information about the machine output can be viewed in a clear dashboard (figure 2.3). The user can easily switch between the different machines, compare them, and even view the live output of other companies that use EVI on their Voortman machines. Furthermore, EVI is always running, when the machine is on, off, running, or waiting for an operator. She also keeps track of these actions and shows those actions nicely in the application.

Secondly, EVI decreases the downtime of the machine. When a machine suddenly stops running, due to a safety interruption for example, EVI recognizes that and will trigger a notification to the operator. He then knows that the machine stopped running, and can act upon that. EVI also gives insight into what the problem of the downtime was, in this case the safety line was interrupted. Other machine statuses can be found in figure 2.4, where the data of 8 March 2024 of the V623 (plate machine) can be seen [7].

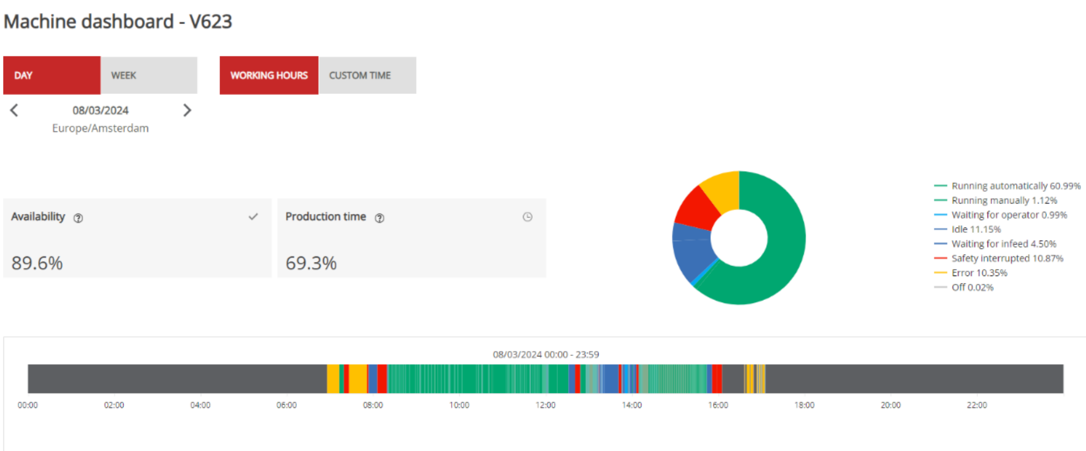


Figure 2.4. Machine status V623

Furthermore, EVI improves the efficiency of the production process as the application supports unmanned production. The operator does not necessarily have to be close to the machine and look at the dashboard the whole time to check if everything goes well. EVI will notify them if the machine stops running, while in the meantime the operator can do other work. However, this feature is not yet actively in use in the workplace.

2.2.2 Live Machine Output EVI

In EVI, the live outputs of the machines are displayed. This output is basically everything the machine ejects and what can be measured. This also means that a clear overview of the output can be made of a certain period in the past, to see how the machine performed in the last few weeks for example. This can be seen in the figure below, which contains information

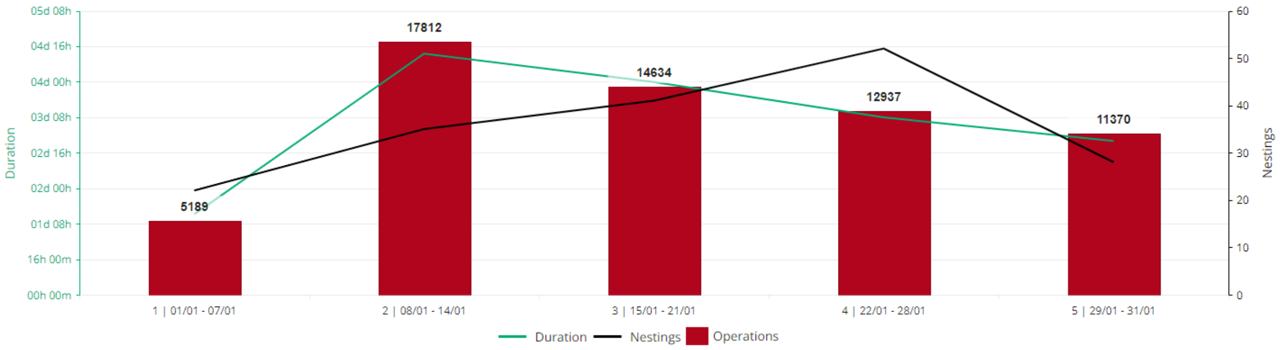


Figure 2.5. Plate machine output January 2024

about the output of a plate machine in January 2024. The duration, the nestings, and the operations are displayed. The duration stands for how long the machine was running, and the operations for the amount of operations the machine has executed. A nesting is a drawing, on a steel plate in this case, where the shapes that need to be cut out are drawn efficiently. This can be seen in figure 2.6. This reduces the amount of waste and increases the production efficiency.

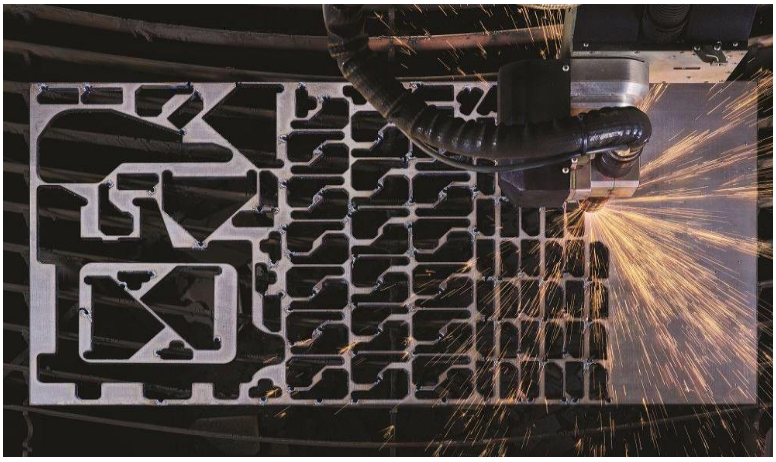


Figure 2.6. Steel plate nesting

Furthermore, the different operations the machine executes can be seen. This includes counter sinking, drilling, marking, milling, oxy-fuel cutting, plasma cutting, and tapping. EVI measures the amount of different operations per hour and displays it in a bar graph. The duration of the operation is also included, which can be seen in figure 2.7.

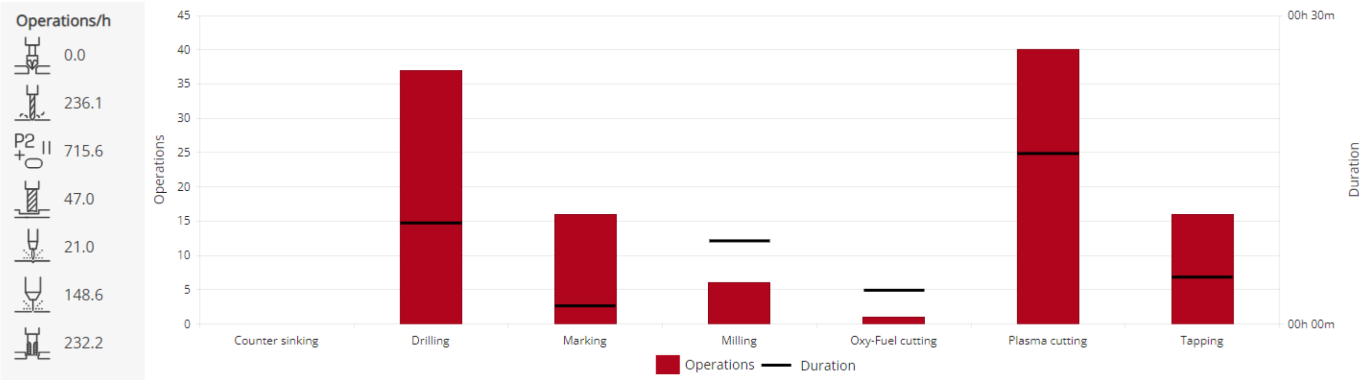


Figure 2.7. Insights in operations

Different machines have different outputs and measuring units, to provide more specific insights in the performance of the machine. In a conversation with the Functional Analyst and Product Owner of EVI, these outputs were explained, especially how relevant they are when telling something about the output of a machine. This information is put in table 2.

Machine type	Outputs	Measured in	Relevance for output
Plate machine	Operations	Operations/hour (holes drilled for example)	High, as can be seen specifically what the machine did the last hour, and how much of it.
	Nestings	Amount of nestings	Low, as each nesting is different. One nesting might need 10 operations, while the other needs 200 operations.
	Duration	Minutes	Moderate, as the duration is the time how long an amount of operations take.
Beam Machine	Operations	Operations/hour (holes drilled for example)	High, as can be seen specifically what the machine did the last hour, and how much of it.
	Weight	Tonnage	Low, as for example 1 hole is drilled in a heavy beam, it will be measured that the machine processed a lot of tonnage. In theory this is true, but in fact the machine only drilled one hole.

	Products	Products that are fully processed	Low, as this only counts fully processed products. These products really differ in how much they are processed, so do not give a right indication of the performance.
Fabricator	Weld volume	Cm^3	High, as it measures how much the machine actually welded, no matter how long it takes or what products.
	Cycle time	Time the product is on the machine till it is finished	Low, as the cycle time also goes up when the machine is not running, at night for example. This gives a distorted view of the performance.
	Products	Amount of products that are welded together	Moderate, as the products have (mostly) a linear relationship with the welding volume.

Table 2.2. Machine output specification

The operations and the weld volume have the highest relevance for the machine output, thus they are further analysed to see what factors have an influence on these outputs. These factors are determined in a conversation with the Functional Analyst, but also by conducting interviews with some people. The four most important ones are the uptime of a machine, so how long the machine is running effectively; the material that is processed, as some operations can be done faster on different material; the machine settings, for example how fast the drill speed is; and the tooling, which is more about the using the right equipment for a certain operation.

To find the factor that contributes the most, changes should be made to these factors to see what influence they have on the amount of operations. As it is not possible to actually test these changes, it is done hypothetically.

Uptime

With the data in EVI, a calculation can be made how much operations are done on average per hour. The duration and the amount of operation is known, so we can divide them to know the operations/hour. The results can be seen in table 3, and the data used comes from the plate machine of Voortman, from 22/04 – 26/04 (figure 10).

Date	Duration	Operations	Operations/hour
22/04	12h 53m	1799	140
23/04	11h 32m	1455	126
24/04	14h 47m	2638	178
25/04	17h 24m	3572	205
26/04	04h 46m	1038	219
Average			173,6

Table 2.3. Operations/hour of plate machine

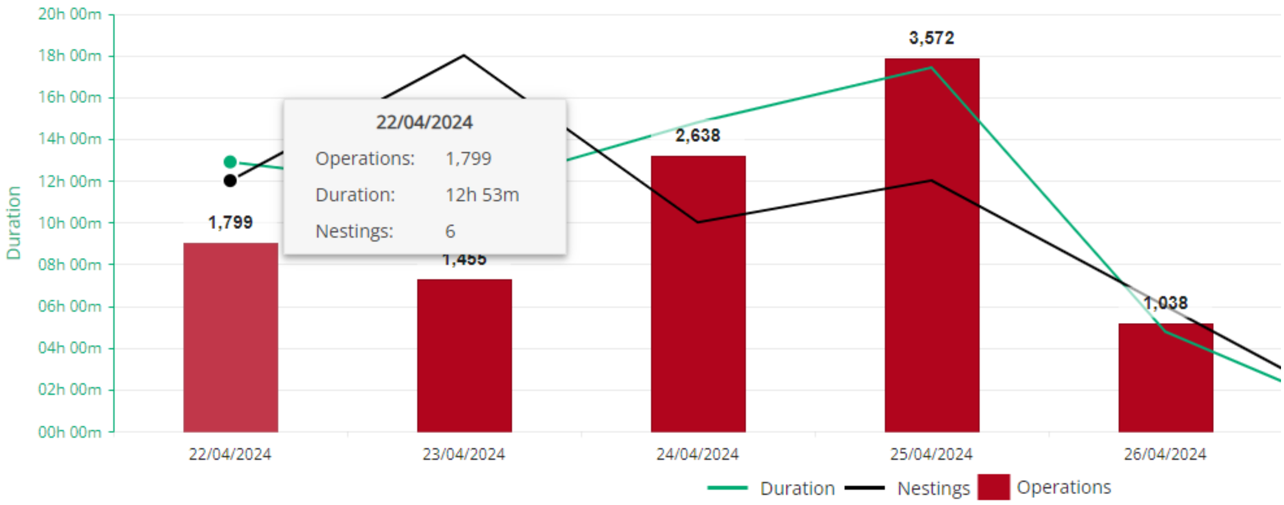


Figure 2.8. Output plate machine 22/04-26/04

It can be seen that per hour, an average of 173,6 operations are done. This means that if the uptime of this machine increases with an hour every day, around a 1000 operations will be done more per week, which makes a significant difference.

Material

Moving on to the material that has to be processed. Changes in material thickness or using other material does have an impact on the machine output. However, the thickness of a material cannot simply be adjusted, as it has to meet certain requirements which include strength. This is also the case with using other material. And if there is for example a material that can be used and faster processed, the impact on the amount operations would never be as significant as the uptime, as time profit would be minimal. Also, within Voortman, they already mostly use the optimal material and thickness, as they have a lot of experience with steel processing.

Tooling

This applies also to the tooling. Of course, improvements can be made by using higher quality tools for example, but that will also increase the production costs. The time profit that will be achieved would be minimal, and not worth it as the tooling is already close to optimal.

Machine settings

Continuing with the machine settings, it does have an impact on the amount of operations, it is only hard to identify how much. For example, when you increase the speed of the drill or the saw, the amount of operations will increase. However, there is a limit to it. Increasing the speed of the tools will cause more wear, which will reduce the RUL (Remaining Useful Life) of a tool. This means that the tool will break faster, which causes more maintenance and an increase in production costs. Therefore, the ultimate relation between machine settings and the RUL should be found, to have an optimal production. The optimal machine settings are known at Voortman, so the optimal machine output can be calculated. This can then be compared to the actual output, to see how close customers are to optimal production output.

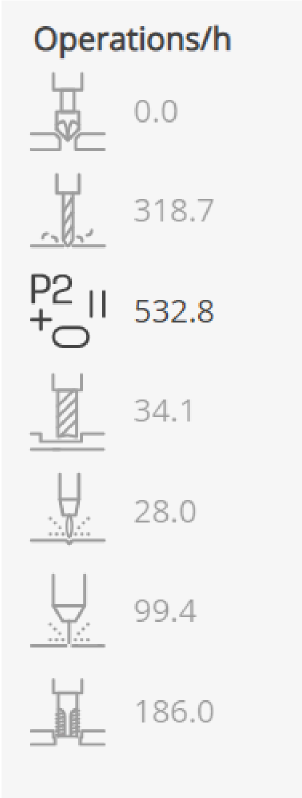


Figure 2.9 Average operations/hour in EVI

2.2.3 Conclusion

In conclusion, the uptime has the most impact on the amount of operations, as can be seen in figure 2.9. There, the average operations per hour can be seen of the month June. By increasing the uptime with an hour per day, these numbers will be doubled, which is a great impact. Further research should then be done on how to increase this uptime. Tooling and material choice could have a small impact on the amount of operations, but it is hard to change and identify how much effect it really has. Furthermore, they are close to optimal, so not much profit can be gained there. Tweaking the machine settings also contributes to the operations, but then the ideal relation between the settings and the consequences of it (production costs, and maintenance) should be found. But when comparing the actual output with the optimal output, conclusions can be drawn on how optimal the production output is, and possible changes can be made to bring the actual output closer to the optimal output.

2.2.4 Future of EVI

As EVI is still in the development phase, there are plenty of features yet to come. To get an idea of what the future of EVI looks like, an interview with the product owner of EVI is conducted. He showed and explained a timeline of how the development of EVI will look like for the coming year with the different features that are planned to be implemented. The features listed below are for now the most important and relevant.

Automatic Reporting

To easily check how the machine performed last week, an automatic reporting feature will be added. This report will be made at the end of each week and gives a clear overview of the performance of the machine. What the availability was, what the actual running time was, how many operations the machine has done, etc. Furthermore, with this feature, it can easily be seen if the machine performed better or worse than the week before by comparing the reports.

Predict the next manual action

To increase the efficiency of the machine even more, the next manual action can be predicted with this feature. This means that EVI knows beforehand when for example, a tool has to be replaced by an operator. EVI will notify the operator that the tool needs to be changed in 5 minutes, and the operator can already prepare for changing the tool when the machine is still running. This means that the downtime of the machine will be decreased, leading to more efficient production.

Using the data EVI provides for other applications

Steel manufacturing companies that have bought a Voortman machine, might not want to use the dashboard of EVI, as it is not relevant for them, or that they already use their own application to get insights into machine performance. That is why the EVI team came up with an idea that allows other applications to use only the data of EVI, without having to use the application itself. This data can then be implemented into their own application, so the companies do not necessarily have to switch to EVI.

Energy consumption

Another feature yet to come in EVI is to provide insights into the energy consumption of the machines. By knowing this consumption, areas where energy is being used inefficiently can be identified. When acting upon that, the production costs can be reduced which leads to more profit or lower selling prices. This may appeal to environmentally conscious clients to buy a machine at Voortman. Furthermore, insights into energy use can help to ensure compliance with the energy and emission regulations.

Tool usage & inventory

Furthermore, tool usage will be a coming feature in EVI. This feature will show how many tools are used in a period, and will also keep track of the inventory. When a tool is almost running out, new ones are automatically ordered. Based on this data, the customer can adjust the dynamics of the machine. It is similar to the dynamics of a car, which has a sports mode, an economic mode, and a comfortable mode. When a company does not care about the costs of the tools but wants to produce as fast as possible, the machine will be in 'sports mode’. This will eventually lead to a high tool cost because the tools will break down more quickly when the machine is running faster. When a company is not focused on producing as fast as possible, because they just don’t need to, the machine can be set to ‘comfortable’ or ‘economic mode’. This way, the tool usage will be lower which decreases the tool cost.

Preventive maintenance within EVI

In the future, preventive maintenance is also planned to be added to EVI. This means that in EVI, the operator or the plant manager can see beforehand when and where the machine needs maintenance. With this feature, maintenance can be planned much more efficiently, which also increases the efficiency of the production process and reduces the failures and defects of the system. This has also already been done by TATA Steel, where they predicted bearing wear with data-driven models [8].

2.3 State of the Art

Currently, one of the main developments in the steel industry is the implementation of technological advancements, also known as Industry 4.0. This includes the automation and digitalization of manufacturing processes, leading to improved production efficiency and quality [9]. As the solution should guide customers to optimize their machine output using EVI, research is conducted on what already exists when it comes to data collecting and output optimization in the manufacturing industry, and how that can be converted into a sort of decision support system for production managers that use Voortman machines, to guide them in this process. To get more insight into where this development currently is and what is already out there, the state-of-the-art of this topic should be created. This will be done by looking at other companies, techniques, or products from which inspiration can be drawn, or to prevent that the wheel will be invented again.

2.3.1 Collecting machine data

In order to optimize the machine output, insights in the output are needed. To acquire these insights, data of the machine should be collected on how the machine performs. There is a huge difference between industries and companies on how that is done, as the data that needs to be collected differs a lot. That is why the focus lies on collecting data in the manufacturing industry.

SmartWire-DT (Eaton)

Eaton designed this intelligent wiring system to connect different components inside and outside the control panel. This saves a significant amount of time and money when setting up the machine, especially the wiring. Communication with all components is possible, and the point-to-point wiring errors that may occur are also solved by SmartWire-DT (figure 2.10). The most important feature is that data can be collected from all the connected components, which leads to detailed, real-time data for the users. With this data, users can implement preventive maintenance as they have real-time data on the status of the machine. This way, the productivity and the system availability can be optimized when using the SmartWire-DT [10].

Figure 2.10. SmartWire-DT intelligent wiring solution

Field System Basic Package (Fanuc)

This 'all-in-one' box is an integrated information infrastructure for manufacturing data, which has the same idea as EVI. This system provides valuable
insights into digital data of manufacturing machines. It is not only applicable to their own CNC machines and robots but can also be implemented in other companies. It is easy to set up at a production site, by setting its IP address, the controller model, and the port number. Once connected, the system will start collecting data and create common data models out of the models from different companies, which can be seen in figure 2.11. This data will then be

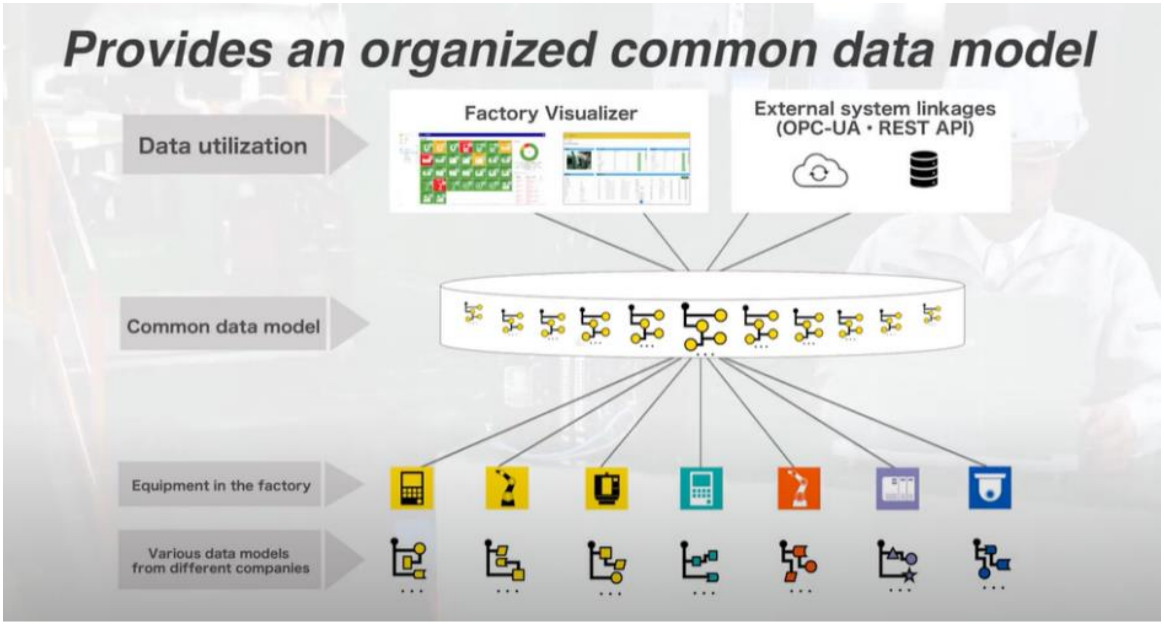


Figure 2.11. Field System Basic Package Fanuc

visualized in a dashboard,

where people can see the data that has been collected. [11]

2.3.2 Visualizing machine data in manufacturing processes

It is important to collect data on the manufacturing process, but it is only valuable when it becomes visible. This way, the machine or plant managers have insights into this data and can make decisions based on that, to improve efficiency and quality or to reduce the costs and downtime of the machine. There are many different techniques to visualize this data, and a few implementations are listed below:

Smart Services - Cool Industries

Smart Service is an online remote monitoring service that displays the data collected from their coolers in a clear dashboard, giving quick insights in the historical and actual performance of the products. Smart Service uses these real-time information to define causes of failures, even before they become a problem. This is also called ‘predictive maintenance’. This prevents unexpected production stops that hinder the productivity.

Furthermore, a personal dashboard can be made to get more insight into the performance of a specific cool installation, and to receive advice on how to improve the efficiency of the cooling processes. This will lead to cost reduction and improvement in the quality of the installation [12].

In the steel manufacturing industry, maintenance is one of the main reasons of downtime of a machine. If this maintenance can be predicted using a service like Cool Industries does, the maintenance can be planned and executed much more efficiently, leading to a decrease in the downtime of the machine.

Andon Toyota

Andon, the Japanese term for “light” or “lamp”, is a technique introduced by Toyota in the manufacturing process. In Lean manufacturing, a method that aims to reduce waste while increasing productivity [13], an Andon is a tool that notifies workers of issues occurring within the production process. This technique is part of Jidoka, which means “automation with a human touch”.

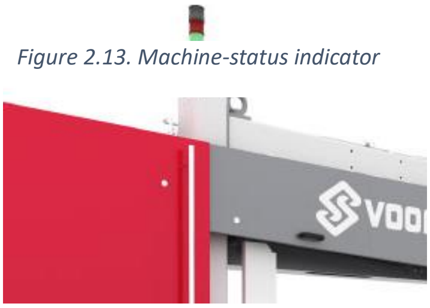
Color-Code	Condition	Action
(green)	Production is normal	Proceed to the next step
(yellow)	Problem appeared	The problem cannot be identified and will need further investigation
(red)	Production has stopped	An operator needs to have a supervisor check the facility

Figure 2.12. Andon color code

The first version of Andon consists of cords, which the workers can pull when there is a problem in the production process. The supervisor notices that the cord has been pulled, and can review the issue that occurred. The signal is color-coded, meaning that the supervisor knows what action needs to be taken (figure 2.12). This is the same idea as the light indicators on the Voortman machines, where the machine status is represented by colours and can be seen from a distance (figure 2.13).

The cords and colours have changed into complex dashboards, where an overview of the production status can be seen and where the location and cause of an issue can easily be identified.

Figure 2.13. Machine-status indicator



Applying Andon in the workplace has several advantages. First, by quickly addressing the issue and identifying where this issue is located and what the cause is, swift action can be taken to resolve the problem. It also provides a clear overview of the production status.

Furthermore, Andon encourages workers to report problems rather than hide them for fear of judgment. This will improve safety, and increase the efficiency of the production process and the product quality [14].

APM Reliability (GE Vernova)

APM (Asset Performance Management) Reliability is a solution that provides predictive diagnostics based on analysed data, to detect issues before they become a critical problem. This allows companies to plan maintenance more efficiently, and will eventually reduce unplanned downtime and costs in the manufacturing process. These diagnostics are presented in a clear dashboard, where the teams can collaborate with each other, leading to better decision-making.

Furthermore, APM Reliabilty makes use of digital twins, which is a virtual representation of (parts of) the physical manufacturing process. This is done to monitor and analyse the performance and behaviour of a machine, which leads to better insights in problems that might occur, or processes that can be done more efficient.

Another technique in APM Reliability is the root cause analysis (RCA). With this analysis, a better understanding of the cause of failure is provided, to resolve it faster and to prevent it to happen in the future.

Figure 2.14. APM Reliability dashboard

Using APM Reliability will provide actionable feedback to the user based on analyzed data, which leads to the implementation of predictive maintenance and the possibility to execute digital, simulated tasks. Furthermore, the user gains more knowledge about the causes of failures, and how to resolve them [15].

Aspen Mtell Software (AspenTech)

The Mtell software of AspenTech is also design for APM. It combines multiple technologies such as AI, data analytics and machine learning to not only prevent and predict potential failures of a system, but also to provide advice on actions that can be taken to decrease the downtime and failures of the system, leading to less costs and unplanned maintenance.

One of the key features of the Mtell Software is the configurable KPIs (Key Performance Indicator) & dashboards, which provide quick, clear insights in both the plant and the business performance. Users can easily access the specific data they want to see, including maintenance costs, overall performance, and the decision support system. Mtell is the only solution on the market that gives users the option to personalize the dashboard and KPIs to their specific needs. This way, tailored advice can be presented to the user to optimize their system even more [16].

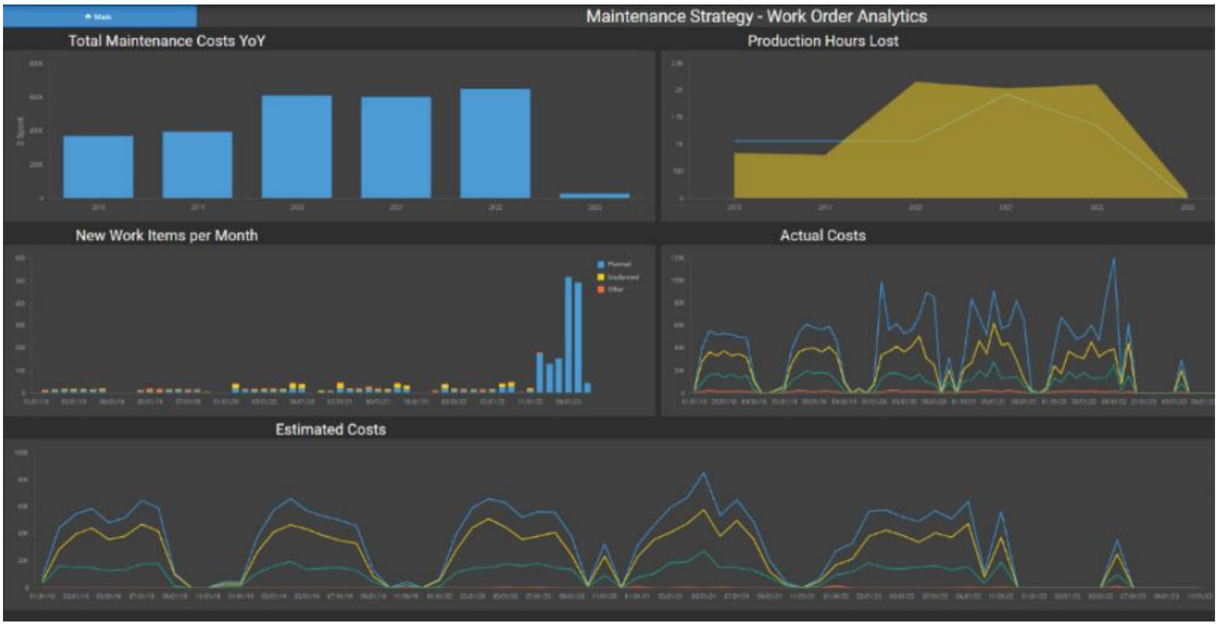


Figure 2.15. KPIs and Dashboards for Aspen Mtell

2.3.3 Analysis

In conclusion, Industry 4.0 is witnessing significant developments and implementations in the manufacturing industry. More and more companies are striving towards digitizing and automating their manufacturing process, leading to a more efficient productivity and higher product quality. To achieve this, machine data must be collected and visualized. A few companies and products are described and analysed to see how they do it, and what the latest developments are. This involves several techniques, such as light indicators and preventive/prescriptive maintenance, to get live insights in the machine status and health.
In figure 2.15, insights in the estimated and actual costs are provided. These two can be compared, and it can be easily seen whether the costs correspond, and a decision can be made to decrease or increase the costs. This may also be applicable in the steel industry, where the actual uptime is displayed against the optimal uptime, to see whether a customer is producing optimally. Based on this comparison, advice can be given to increase the actual uptime.
Another interesting method is the use of a digital twin, which serves as a digital representation of a machine or system. Simulations and processes can be executed on this

digital machine, and the results can be seen without having to test it on an actual machine. This technique is currently in development at Voortman, and will play an important role in the future. Furthermore, the Root Cause Analysis can help customers to reduce the downtime of their machine, by quickly resolving the failures of the machine.
As the research question is about providing actionable feedback to the user, predictive and prescriptive maintenance are the most interesting topics to continue research on and to see how it might be implemented at customers of Voortman.

2.4 Literature Review

Introduction

DIGI-STEEL, a startup within the Voortman Steel Group, focuses on cloud-based software solutions for their steel processing machines. Their goal is to improve the production efficiency of these machines, recognizing that time is a crucial asset in production. Through their software, they try to optimize the production output of their customers by integrating processes, data, and human interaction. EVI, an application that is part of Voortman's Smart Industry initiatives, provides live machine insights through a clear dashboard, helping in further performance improvements of the steel processing machines, and guiding customer factories into the Industry 4.0 era.

As EVI already provides valuable insights into machine performance and output, it can still be hard to identify how to improve this. That is the reason why they want to assist the production manager in this process on how this improvement can be realized, by providing guidance and actionable feedback. This goal leads to the following research question: ‘How can actionable feedback be provided for production managers to optimize the machine output in an ICT-based tool, to be integrated in EVI?’

To gain more knowledge about the background and environment of the goal, literature research will first be conducted on Industry 4.0, which can be defined as the integration of intelligent digital technologies in production processes. It contains the implementation of modern technologies, such as the Internet of Things, Artificial Intelligence, robotics, big data, and automation [17]. This includes the implementation in the steel manufacturing industry. To get more specific and to find inspiration to answer the sub-questions, further literature research will be conducted in the second part of this paper on reducing the downtime of manufacturing machines with a focus on maintenance management, as maintenance has a huge impact on downtime [18].

Industry 4.0

The manufacturing industry has entered the fourth industrial revolution, Industry 4.0, also known as Smart Industry. This concept focuses on automation, digitization, and data exchange in manufacturing processes. Industry 4.0 aims to digitally connect all elements along the entire manufacturing process, from raw materials and pre-products at the beginning down to finished products, logistics, and even customer feedback in the end [19]. Furthermore, monitoring and capturing real-time data is an important topic of Industry 4.0. This data, collected by sensors, gives more insights into the machine's status and performance [20]. This data is stored in the cloud, so machines or other stakeholders can use this data to make the right decisions, also called data-driven decision-making. This will eventually lead to an increase in production efficiency and business growth, while at the same time, the production costs will be reduced [21].

So, Industry 4.0 is the future of manufacturing, but what is the effect on the steel manufacturing industry? In Europe, most steel experts say that the steel sector has already been digitized a lot. And it’s only going forward, as there are many more data sources embedded in the production process, because of more advanced sensors and measuring technologies. This also includes monitoring and capturing real-time data from machines, which gives steel manufacturers the possibility to act upon this data and improve the production process. Another advantage is that companies can implement predictive maintenance models for their machines, which reduces downtime and the risk of failures of the machines. The quality of the product that has been manufactured can also be improved, as defects or irregularities can be detected more easily [19]. Not only steel manufacturing companies are interested in the upcoming Smart Industry, but also governments see potential in the Industry 4.0 era. They are putting a lot of effort into this concept to boost their economies, and even specialized platforms are set up, such as the Smart Factory of ESTEP. This is the European Steel Technology Platform, which some steel manufacturing world leaders are a part of, such as Tata Steel and ArcelorMittal. They are focused on the transformation into Steelworks 4.0 and the creation of Cyber-Physical Production Systems (CPPS). This involves inter-connected physical components, such as steel processing machines, weld robots, sensors, cloud-based software, and databases, and leads to the digitization of the entire supply chain in the steel industry [22].

Reduce downtime

As mentioned, time equals money, especially in the manufacturing industry. Heavy machines that are not running increase the costs significantly. This is called downtime, which can be defined as the time a machine is not functional or is not running while it should be. There are several causes for downtime, such as machine breakdown, maintenance, lack of materials, and failures [23]. That is why downtime has a great contribution to system inefficiency within a manufacturing process. The ideal goal of companies is therefore to achieve near-zero downtime for the machines [24].

Maintenance management

As Industry 4.0 is integrating into the steel manufacturing industry, maintenance has become more important and has a huge impact on the downtime in manufacturing processes. The contribution of maintenance to the total operating costs is ranging from 15% to 60%. The causes of this are that the interactions between machines and computers are increasing and becoming more complex. Furthermore, new technologies are introduced and the amount of data gathered is increased significantly [18].

There are several solutions and methods to efficiently manage the maintenance of a machine or to reduce the downtime of the machine due to unplanned maintenance. As mentioned, manufacturing companies want as little downtime as possible, as maximum throughput is the priority. Furthermore, according to Nunes et al (2023), applying effective maintenance strategies reduces the production costs, and may even increase the lifetime of a machine.

One of the strategies is the reactive or 'run-to-failure' approach, also called Corrective Maintenance (CM). These are the first 2 levels of maintenance from Figure 2.16. This means that the machine runs until a problem occurs, and only then maintenance is executed to get the machine running again. This seems logical, as the machine is running as much as possible. However, as the pressure increases on enhancing productivity, and the costs of unexpected machine failures increase, production managers step over to the proactive approach to ensure interrupted production. This approach focuses on Preventive Maintenance (PM), which means that the machine stops running for a certain time, and the mechanics inspect the machine to see if there are any critical parts they have to replace to prevent failures and breakdowns of the machine. This falls under levels 3 & 4 of the maintenance levels in Figure 16. The disadvantage is that tools or parts sometimes are replaced when they are still in good condition, leading to unnecessary costs [25].

As the development of technology and Industry 4.0 continues and data monitoring tools become more available, another maintenance strategy emerged, which is called Predictive Maintenance (PdM). This is a condition-based strategy, meaning that the inspections are done by sensors and other technical devices, instead of a mechanic. This way, signs of failure can be detected and identified, and a prediction can be made on when an error occurs. Based on this data, decisions can be made to resolve the failure before it becomes a critical problem, which leads to less unexpected maintenance, and thus less downtime.

Furthermore, insights into the Remaining Useful Life (RUL) of materials and machine parts can be gathered, to know more about the remaining durability of the tool. Maintenance can then be planned more efficiently, reducing the downtime of the machine. The PdM strategy

also decreases the maintenance costs by up to 30% and prevents the amount of machine breakdowns by up to 75%, compared to PM [26].

There is another step further, which is prescriptive maintenance (PsM), the highest level of maintenance. This is a follow-up of PdM and serves as a data-driven maintenance planning paradigm [27]. It presents advice to increase the RUL of a tool or machine, based on the predictions of PM, for example, to reduce the drill speed or to use other tool materials.

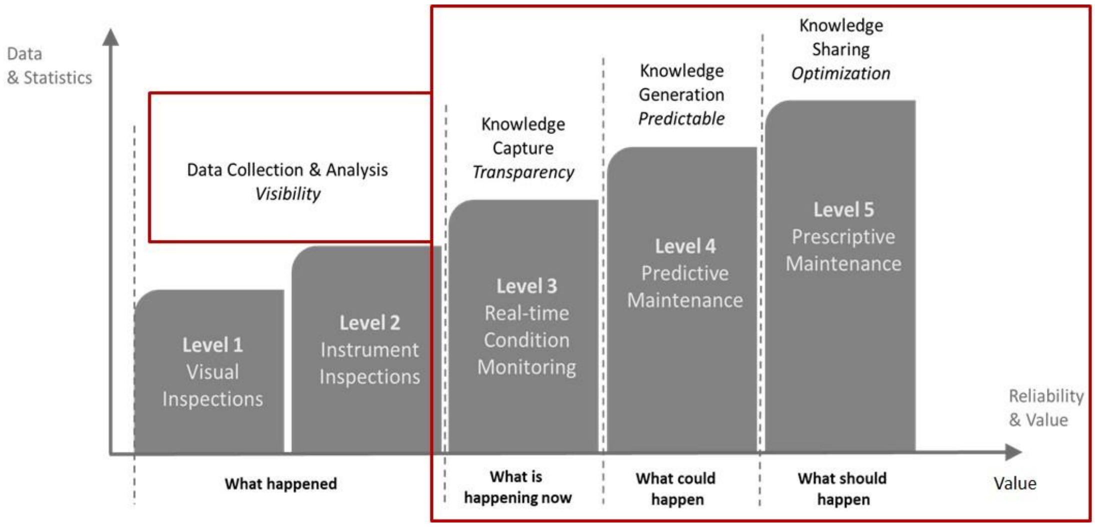


Figure 2.16. Maintenance levels

Furthermore, it may advise on how to increase product quality or machine availability. In this manner, the product quality and the durability of the machine and tools increase, leading to better products, less unplanned maintenance, and a reduction in downtime [28].

Another advantage is that PsM is a continuous loop, which can be seen in figure 2.17. It starts at the bottom, where
data is collected from the shopfloor and pre-processed to derive meaningful information from the gathered data. In step 2, this data will then be analysed and simulations will be done to build a predictive model to detect failures and breakdowns of the

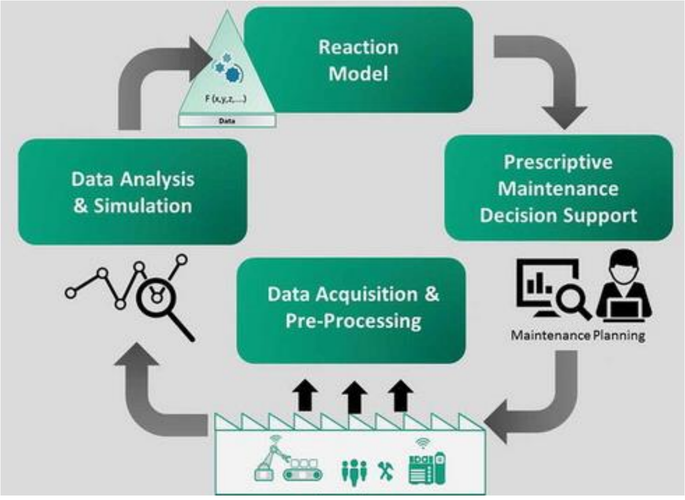


Figure 2.17. Four-step methodology of PsM

system. Step 3 focuses on creating decision rules that meet the specified criteria, based on the outcomes of step 2.
These criteria differ per company and shop floor. In the last step, a prescriptive maintenance decision support system is set up for the user, based on the decision rules of step 3 [29].

A disadvantage is the realization and implementation of PsM in the manufacturing industry, as loads of data need to be collected, monitored, and analysed. Furthermore, according to Padovano et al (2021), another challenge is to combine integrated planning models with production, maintenance, and quality aspects. This results in longer planning times and a reduction in machine availability. Also, the planning is generally done by separate teams and stand-alone software, which makes it harder to use that data or to combine it with another technique.

However, as the Industry 4.0 era arises, data monitoring and cloud-based engineering technologies are developing quickly which means that prescriptive maintenance will be more and more implemented in the coming years.

An approach to apply PsM in the manufacturing industry is done in Austria, on triaxial machining centres of an automotive manufacturer. A prescriptive maintenance decision support system is developed, consisting of four modules in a dashboard. These are the overview, the machine condition prediction, planning support, and a KPI board (Key-Performance Indicator). In the overview dashboard, each machine and its corresponding status and production layout can be seen, and when failure is expected, the status will turn orange. The production managers know that the machine will probably break down soon, and can take action to prevent that based on the advice the system gives [26].

Another implementation of PsM was done by Padovano et al (2021), where they established the missing link between PsM and Production Planning & Control (PPC) in the Cyber-Physical Production Systems industry. This industry includes systems that combine physical components with digital components. It is used in various industries, such as the steel industry. Examples are machines, robots, and sensors. Those are physical objects that collect and monitor data to automate and monitor the production process [30].

An integrated framework has been established and a prototype has been developed, to find the missing link between PsM and PPC, and to explore the challenges, benefits, and feasibility of the implementation of smart maintenance in the CPPS industry.
The prototype of this smart maintenance system consists of two modules, the Machine & Tool Monitoring System and the Predictive Analysis module. The first one collects data on the status of the machines and (historical) failures, while the second module focuses on analysing the RUL and the remaining operating time between failures (ROTBF). This data

will be passed on to the digital twin, which represents an accurate, digital representation of the machine line and can simulate outputs and changes in the production process with this data. The output of the digital twin will be passed on to the Recommender module, where it is converted into suitable inputs for the decision support system, where the prescription takes place. Recommendations of actions are presented to the user and can be executed or rejected. This information is collected and transformed into feedback to improve the recommendations. All the data that is collected is gathered in a decision support dashboard where it is displayed, using different graphs and colors. This includes insights into machine performance, the status of machines, simulation results, and the recommendations [27].

Conclusion

Industry 4.0 is in full development, but there are still many challenges, where one of them is visualizing the collected machine data and converting it into actionable data.
That is why this research underlines the importance of Industry 4.0 and the impact of its implementation in the steel manufacturing industry. By digitizing and automating this industry, companies or machines can form decisions based on data that has been collected along the process. This will lead to an increase in production efficiency and business growth.
Furthermore, a deeper dive is taken into optimizing production output based on Industry 4.0. One of the main solutions to do so is by reducing the downtime of a system or machine, which is the time that the system or machine is not running while it should be. This can be caused by failures, safety errors, etc.; anything that stops the machine from running. One of the main reasons of downtime is maintenance, and by managing and planning this maintenance efficiently, downtime can be decreased. There are several types of maintenance to improve this problem, which are Corrective Maintenance, Preventive Maintenance, Predictive Maintenance, and Prescriptive Maintenance. Especially the last two types are in development and not implemented much yet, as there are still challenges such as data collection and monitoring. However, they provide a potential solution to efficiently perform maintenance. Prescriptive Maintenance goes even a step further, by providing production managers with actionable feedback, to further improve the machine's performance. This is done by presenting the data from predictive maintenance in a decision-making support system, which can be a dashboard or application where the data is shown with graphs, bars, and colours to provide insights into the performance of the shop floor. This type of maintenance seems to be the best suitable in this project to provide actionable feedback to the production manager.

2.5 Interview results

To give an overview of the expert's opinion, the results of the interviews are analysed and can be seen below, and the questions can be found in the appendix. As the interviewees have different functions and perspectives within Voortman, the results are divided into two categories: Production and sales. The interviews were conducted to get more information about the current situation at Voortman, but also what improvements are already done to increase the machine performance. Furthermore, by conducting interviews with customers from an external company, their wishes can be identified to see what they want to see when it comes to machine data.

Function	Category	Company
Production Manager	Production	Voortman Parts Manufacturing
Production Manager	Production	Severfield
Production Manager	Production	Reijrink
Product Specialist Beams	Production	Voortman Sales & Engineering
Business Unit Manager Plate Machines	Sales	Voortman Sales & Engineering
Sales Manager	Sales	DIGI-Steel (Voortman)

Table 2.4. Interviewee description

2.5.1 Production

To get more knowledge about the environment and work of the target audience, the machine output and how to optimize it, interviews have been conducted with several production managers and specialists of different companies which use Voortman machines to get more perspectives on this.

To start close, an interview is conducted with a production manager of Voortman Parts Manufacturing (VPM). VPM uses Voortman machines, which makes him a sort of internal client. He keeps the production process on track and makes improvements where possible. Further information on production managers can be found in section 4.1.3.
When it comes to EVI, he said that he uses it mainly for the machine statuses and uptime, to see how the machines are performing and what the causes are when the machine breaks down.
There are several things that are already done to improve the uptime of the machines. An improved plate nesting algorithm is applied, which only makes use of full plates instead of cutting a part of it, put it away and cut it again later. This saves a lot of time in the material infeed process, which increases the productivity. Furthermore, the tool holders are placed more efficiently, with all the tools needed at the same place. This way, the operator does not have to walk back and forth to get all the tools needed, which eventually reduces the maintenance time of the machine.

To guide customers in the optimization process, he provided a few potential ideas. The first one is to specify the errors more, so that it becomes clearer what the problem is and where it is located. This is called Root Cause Analysis, also discussed in the state-of-the-art.
Another idea was to provide a weekly report to the customer with recurring errors, and the performance of the machine measured in uptime. With this solution, customers can get rid of errors that occur frequently, and compare the uptime of different weeks with each other.
An important aspect to keep in mind, is to ask the customers how they are currently using the machine, and what their production goals are. This information can then be used to provide tailored advice to increase the uptime.

Speaking of optimizing the machines, an interview is conducted with the Product Specialist Beams. He is responsible for the development of new beam machines and continues to improve them for up to 5 years afterwards. In the nearby future, he will also use EVI, but for now they test the machines and products on a small scale themselves.
He also mentioned a few important aspects why the machine is not running optimally. First, the way the operator controls the machine is 9/10 times the problem. The machine needs constant material infeed, but the processed steel also needs to be removed from the machine, in the right order. When doing this wrong or not efficient, much valuable time is wasted. The second aspect is the way the machine settings are adjusted, as production managers and operators have different goals. The production manager wants the output to be as high as possible, while the operator prefers to not increase his cognitive load and just performs the tasks he should do.
A possible solution to this issue is to create a link between the actual performance in EVI and the current machine settings, to compare those to the optimal performance and settings and provide advice based on that information. This way, customers gain quick insights in how optimal the actual machine performance is, and what to change it to reach the optimal performance. These optimal settings are known by Voortman, and customers have access to the settings so they can change it themselves, if they know what to do.

Furthermore, an interview is conducted with the production manager of Severfield, the company that bought the steel construction division of Voortman in 2023. As his focus lies more on keeping the beam line running, he has different needs when it comes to optimizing machine output. A beam line is a production line where multiple machines are placed after each other, where the raw product goes in at the beginning, and will be fully processed at the end.
The task of the production manager is here to keep the buffer zones filled and to distribute the materials evenly over the machines, so that every machine is working and that the process is as efficient as possible. A buffer zone is the zone where the parts wait to be

processed. When planning this incorrectly, the machines have to wait for each other, leading to more time to process the parts.
That is also one of the main reasons why they don't use EVI at Severfield, because they need information on what to do on beforehand and how long that takes, rather than seeing afterwards how and what the machine produced. Furthermore, in EVI it can be seen how much a machine has done, but not exactly what. When for example two welds are forgotten, it is not clear which ones. That is why he is more interested in a solution that helps him with planning the machine occupation and the buffer zones as efficiently as possible. However, this requires a sort of algorithmic software solution, which is not within the scope of this project.

At last, to get a better perspective from Voortman customers, the production manager of Reijrink is interviewed. Reijrink is a company that uses Voortman machines and EVI, which means that specific questions can be asked about the needs and wishes of them, and how potential concepts can be integrated into his environment.
He uses EVI to get more information about the uptime, also at night, as nobody will be there. A part that needs a lot of time to process can be put on the machine in the evening, so it will be done in the morning.
Furthermore, he said that tonnage does not say anything about the machine output, because if you drill one hole in a big steel plate, it seems like you processed a lot of weight, while in fact you only drilled one hole. Products also give a distorted view on the output, because for example many products can be welded together, but you don't know how much the machine has welded. With the welding volume, you do have this knowledge. This is the same for operations, as they give a better view of the machine output, because you can specifically see what the machine has done in a small period of time.
To increase the uptime of a machine, preventive maintenance would be an interesting method to apply according to him. This way, he has more information when tools and machine parts have to be checked and replaced, and maintenance can be planned much more efficiently. A weekly report with performance information also seems handy, but it should ensure that the correct comparisons are made with the same variables.
Besides that, he is also familiar with the machine settings. However, they have a standard value and are more relevant to the operators. The production managers can guide the operators in this, but in reality, they do not change it much.
As Reijrink also has a beamline, he had the same issue as the production manager from Severfield, namely to distribute the work over the machine evenly. More insight in this could lead to a higher productivity, as the machines will be used more efficiently.

2.5.2 Sales

As the project is about guiding customers in this output optimization process, it also affects the sales department, as they want to find out what customers want, to offer that to them. Therefore, an interview is conducted with the Business Unit Manager Plate Machines, to find out what customers want, and how they can be guided to optimize the machine output.
He is specialized in the latest product developments, market research and the product life cycle management of the plate machines. He looks into how to improve and optimize the plate machines, and how to promote it to customers. To do so, it should be known where customers focus on and what attracts them when buying such machine.
According to him, the output of a machine is important, as most customers want to produce as much as possible in as little time. This output is defined different sectors. Machine manufacturers are more interested in products the machine produces, as they need specific products to build a machine. Steel Construction measures output in tonnage, as there products mostly consist out of long beams without too much operations. For Steel Service Centers, the amount of operations are more important, because they buy steel from a manufacturer, process it, and sell it to the end user.
However, there is one thing they have in common, which is that they want to increase or optimize this output. This can be done by changing the settings of the machine, for example to increase the speed of the drill. This is not yet implemented as customers do not have insights in the optimal performance, and the corresponding machine settings. A solution can thus be to provide advice to customers on what parameters to change, based on data from EVI.

Furthermore, as Voortman sells its own software, an interview is conducted with the Sales Manager of DIGI-Steel, the software part of Voortman. He has insights in the developments and future of Voortman's software, what customers want and how they use it.
His function includes promoting and presenting the software packages of Voortman, including EVI, and delivering business cases to customers to evaluate the benefits, risks and costs when implementing the software. He also makes indications on what the price should be of a specific software package.
To convince customers to buy the software, he should know the needs and wishes of the customer. When it comes to visualizing machine data in EVI, the uptime of a machine is the most important. With this information, the customer can make cost calculations on how valuable the machine and its productivity is. Furthermore, they can compare the output with historical and current data, to see how it is changed.
To help them improve the uptime, a weekly advice report can be provided which shows the machine performance of that week and compares it to other weeks for example. To make a

good comparison, the same variables have to be taken into account to give a fair overview. The advice that is given in this report also differs per customer and per machine. For example, different advice is provided to a customer that wants to produce as much as possible no matter the costs than a customer that wants to produce more economically and sustainable.
Another solution to increase the uptime of the machine is to monitor tool wearing, which means that data is collected and visualized on the RUL (Remaining Useful Life) of a tool. With this data, the customer has insights in how long a tool will last, and when it needs to be replaced to prevent the machine from breaking down. This is also called predictive maintenance. However, it is still a challenge to realize this, as not all the data needed is available yet, but it will sure come in the future.

From the interviews, interesting insights and knowledge is gained. A general goal is that they all want to optimize the machine performance. However, there are different needs at different machines and companies. For the beamline, where multiple machines are standing in line, a planning tool which tells you when to put what material on the machine, and how long it will take, will possibly increase the performance. Other people would like to see a weekly report, which summarizes the performance of last week. Another solution would be to present information on the RUL of tools, to see how long they will last until they theoretically would break. The customers can predict when the tool needs to be replaced, preventing unplanned machine breakdowns. All these different ideas will be evaluated and discussed, to see which one is the best suitable for this project.

2.6 Conclusion

First, an overview of the background research is given. In the beginning, Voortman Steel Group is analysed to get to know the context and the industry better. After that, EVI is explained to get more insight in the context of the graduation project. Then, the state-of-the-art is set up to see what is already out there, and to gain inspiration from other companies and products to apply it to my own project. This continued with conducting literature research on the application of Industry 4.0 in the manufacturing industry, and how to reduce machine downtime within such industries. At last, the interview results are presented to also get the expert's opinion and ideas on several topics. The information gained in one part can be used in another part to support each other.

In conclusion, a lot of useful information and insights are gained from the background research and is used to find answers to the sub-research questions to continue working on the ideation phase.

The first sub-research question was about machine output, what it is and what measuring unit gives the most accurate picture of it. This question can be answered by the literature research and interviews conducted, but also by analysing EVI. Machine output can be defined as anything the machine ejects and what tells something about the performance of the machine. This data is also measured in EVI, where insights are provided into the actual output of a machine. This output is measured differently per machine type. Plate machine output is measured in operations, nestings and duration, beam machine output is measured in operations, duration and tonnage, and fabricator output is measured in weld volume, cycle time and products. However, not all these measurements give an accurate image of the machine output. Some indicate a high output, while the output is actually not that high at all. Fortunately, there are two measurements that provide an accurate view on the output, which are the operations of the plate/beam machines and the weld volume of the fabricator. They indicate what the machine actually has done in a period of time, and do not give a distorted image. After a short discussion, the measuring unit chosen is the operations, as more data is available on that specific output, and because there are more customers that use a plate or beam machine, which makes it more relevant.

This leads us to the second sub-research question, where the focus lies on the factors that determine the amount of operations, and which one has the most influence on it. This is mostly addressed in the conversations with the supervisors from Voortman, but also in the interviews. The factors that do have influence on the operations are the uptime of a machine, the material processed, the machine settings, and the tooling, so if the right equipment is used for the right purpose. After looking at the impact of these factors on the amount of operations, it can be concluded that the uptime of a machine contributes the most. The V310 plate machine on average drills 300 holes/hour (figure 2.9). Assuming the machine has an uptime of 8 hours on a day, this comes down to 2400 holes. If the uptime will then be increased with one hour, the productivity, or at least the amount of holes drilled will increase with 12.5%. This can be combined with the machine settings, as better machine settings will improve the production output and leads to more operations/hour. This means that when increasing the uptime, adjusting the machine settings could be a solution. That is why the uptime is chosen to do further research on, and to see how it can be increased.

This is what sub-research question 3 is all about. Methods to increase the uptime are found in the literature review, state-of-the-art and interviews.
In the literature review, a deeper dive was taken into the reasons of downtime, and how to reduce this. The main finding was that maintenance has a huge contribution to the downtime of a machine, and research is done on how to manage the maintenance efficiently.
Maintenance is also a continuous process, which means that it can’t be resolved with

implementing a solution once, the solution should be continuous. Predictive and prescriptive maintenance were one of them, and are techniques that are still in development. This means that it is not yet implemented at many companies, also not at Voortman. These methods were also addressed in the interviews, and help to plan maintenance much more efficiently, and will prevent critical failures of the machine by replacing a tool on time. The unplanned maintenance will reduce, leading to less downtime.
This solution is supported by the state-of-the-art, where a few examples are mentioned from companies that already tried to implement this type of maintenance management. However, not many details were given on how to do it or how to present it to the target audience. Furthermore, the state-of-the-art provided another solution, which is the Root Cause Analysis (RCA). As lots of time is wasted on identifying and locating where the problem is, a root cause analysis can be performed to help operators find the issue, which makes it much easier to resolve. As a solution that includes RCA requires a lot of machine knowledge and a machine learning process, this method might not be suitable for this project. Although, we can still look at the possible implementations in a concept as it does reduce the downtime of a machine.

The main idea that came out of the interviews was an automated weekly report. This report includes performance information, particularities and should be easy to compare with other weeks. The important thing in providing such report, is that the comparison should be correct. The same variables have to be compared to each other, so the production manager can actually see why one week has a lower output than the other week. To stay within the scope of this project, this report should also provide actionable feedback to the user, based on the information in the report.

Which means that there are three potential ideas, a weekly report, prescriptive maintenance and the Root Cause Analysis, which can also be seen in figure 2.18. Further steps are to brainstorm about these ideas and to create concepts out of it. Research on these concepts should be done, and one final concept needs to be chosen. This concept should then be tested and worked out further, using prototypes. In the end, one final prototype should be presented to the production manager.

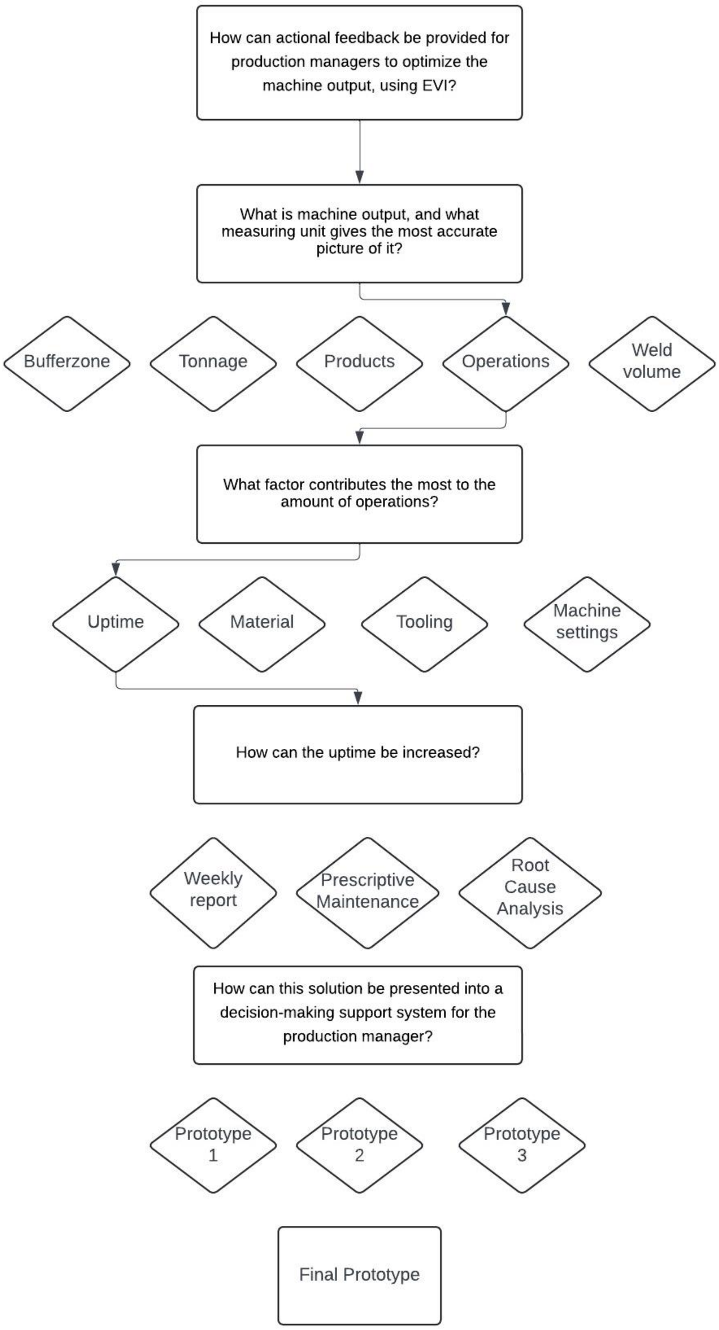


Figure 2.18. Updated GP roadmap

Chapter 3 – Methods and Techniques

This chapter provides an overview and explanation of the different methods and techniques used in this project, which are used to find answers to the research questions and to realize the final prototype.

3.1 Creative Technology Design Process

To have a structured and complete design process, “A Design Process For Creative Technology” is used [31]. It provides guidance in the design process in projects, and consists of 3 phases: Ideation, Specification and Realization. After these phases an evaluation takes place. The design process can be seen in figure 3.1.

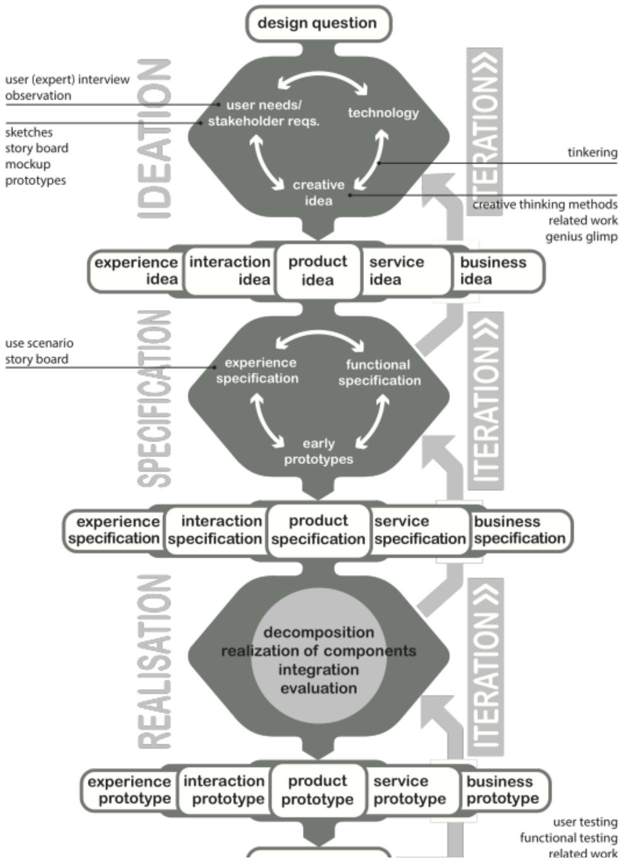


Figure 3.1. Creative Technology Design Process

3.1.1 Ideation

In the ideation phase, a final, creative idea is chosen to answer the design question. The design question is set up on beforehand, based on the problem statement. In this case, the research question is: ‘How can actionable feedback be provided for production managers to optimize the machine output, using EVI?’

After that, background research is conducted to gain the necessary knowledge and information. This includes conducting interviews, state-of-the-art and literature review. Moving on to the ideation phase, the stakeholders of this project are defined, and the preliminary requirements are set up, based on expert interviews. With all this information, brainstorm sessions will be held to find potential ideas to the problem, which in the end leads to one final, creative idea which should then be specified.

3.1.2 Specification

To specify the creative idea, the functional and nonfunctional product requirements will be worked out further using the MoSCoW method, which is explained in section 3.4. This will be done by analysing and interviewing the stakeholders, to get more information about their needs and requirements.

3.1.3 Realisation

In the realisation phase, the first prototype will be created based on the requirements. As the prototype will probably be a clickable dashboard, an application like Figma or Adobe XD can be used. These are web applications specialized in interface design, to create and test different dashboards. While designing the product, interviews and prototype testing can be used to get the expert's opinion, and to further improve the design. The goal is to present a final, working prototype which will guide the production manager in the process of machine optimization.

3.1.4 Evaluation

To find out whether the designed prototype meets the requirements that were set up, an evaluation will be conducted. This will be done by usability testing and functional testing. The usability tests will be executed with potential users of the prototype, which include production managers. The user will be observed during the test, and some questions will be asked afterwards.
The functional test will be conducted mostly by the researcher itself, to check whether all the functions within the application work properly.

3.2 Brainstorm sessions

To come up with potential concepts for the generated ideas based on the background research, two brainstorm sessions will be conducted. The first session will be individual, and the goal of this session is to come up with as much possible technologies as possible, to get a better view on the scope of the prototype, and what feasible technologies are. After that, a selection will be made to identify potential technologies that can be used for the solution. Then, the input of the production manager and the output of the corresponding technique will be mentioned, to see what influence the production manager has and what the technique shows back.

With this information, a group brainstorm session will be conducted. In this session, the role storming technique will be used, which is pioneered by author and consultant Rick Griggs. In role storming, participants of the brainstorm roleplay as someone else during the session, to overcome the natural hesitations that stop people from coming up with creative ideas. This way, people look at the problem or concept from a different perspective, which may lead to more dynamic, out-of-the-box ideation [32].

The results of this second brainstorm will contribute to set up the requirements and features needed in the design, which is important to achieve the goal of the project by creating a prototype that fulfils these needs.

3.3 Interviews

To get more insight into the expert's opinion, interviews are conducted. People from different departments and companies are interviewed, to have a wide variety on perspectives on this project. Two different techniques are used for the interviews, which are semi-structured and unstructured. Semi-structured means that a few questions are prepared on beforehand, but more, open-ended questions can be made up during the interview to get specific information about a certain topic. This technique is more used with arranged interviews, with specific people within the company or from another company.
In an unstructured interview, no questions are prepared. However, the interviewer usually has certain topics in mind where he wants to talk about. It looks more like a conversation instead of an interview. This technique is mostly applied in talks with the supervisors, or people that are in the same office.

3.4 Stakeholder Analysis

To get more insights into which people are involved in or affected by the project, a stakeholder analysis will be conducted. Here, all stakeholders will be identified, what their interests are and how they can have an influence on the project, or how they might be impacted by the project. These stakeholders will be placed on an impact/influence grid, where also can be seen what to do with that certain stakeholder. Should they be managed closely, or should they only be monitored? Furthermore, the target audience, the production manager, is described to get a clear view of who he is, what he is doing and what is goals and wishes are.

3.5 Requirements

To create a working prototype which solves the problem in this project, a list of requirements needs to be set up which should be satisfied by the prototype. As mentioned in section 3.2, preliminary requirements are set up after the ideation phase. These requirements are specified and improved in the specification phase, and divided into functional and non-functional requirements. This will be done by using the MoSCoW method, to get more structure in identifying what has more priority. This technique divides the requirements into four different categories, based on their priority [33]:

- **Must have:** These are critical requirements that the project cannot be completed without them. If these are not fulfilled, the project is considered a failure.

- **Should have:** These are important but not critical features of a project, and these are high-priority items that are not as time-sensitive as the Must-haves.
- **Could have:** These are desirable features that do not affect the overall project's success. Therefore, they can be included if time and resources permit.
- **Won't have:** These features are the lowest priority or are not necessary for the current delivery cycle. They are agreed upon and recognized but are dropped for the project's current timeline [34].

3.6 Educational activities

To gain more knowledge about the history of Voortman, what the company looks like and what other graduates are doing, Voortman arranges educational activities. In the beginning, they organized an introduction session, where all the graduates had to introduce themselves and talk more about their graduation project. This continued into a lunch session, a few weeks later, where the graduates had to present their work till then. In this presentation, the CEO of Voortman talked more about his experiences, and what it is like to run such a huge company, which was interesting to hear.

Furthermore, the supervisor from Voortman guided me through the company, showing all the departments and machines, while explaining them.

Chapter 4 – Ideation

Moving on to the ideation phase, the stakeholders will be identified and described. Furthermore, brainstorming sessions will be held were the three ideas, the weekly report, prescriptive maintenance and Root Cause Analysis, will be discussed to see how they can be implemented, and how they can provide actionable feedback to the production manager. After that, preliminary requirements will be set up and a few sketches of the design will be made, which will be tested afterwards. In the end, one final idea will be chosen ready to be specified.

4.1 Stakeholder analysis

To identify the people that are involved in this project and what impact and influence they have, a stakeholder analysis is done. This gives a better understanding of the needs and wishes of the stakeholders, which makes it easier to engage and manage those expectations.

4.1.1 Stakeholder Analysis Table

To give a clear overview of the stakeholders and what interest and influence they have on the project, a table has been made. The stakeholders are divided into three categories:
Primary: The individuals that are directly affected or have a direct impact on the project.
Secondary: The individuals that are not directly affected by the project, but are still interested. They also have less impact on it than the primary stakeholders.
Tertiary: The individuals that are not directly involved in the project, and might not be interested in the project directly.

Stakeholders	Category	Interest	Influence/impact
Researcher (Myself)	Primary	Creating a solution that guides Voortman customers to optimize their machine output.	High, as I am executing this project
Supervisors	Primary	Providing feedback, resources and guidance to the researcher of this project.	High, as they supervise and set time boundaries in
Production managers	Primary	Reducing downtime and minimize costs	High, as they are the target audience, and the solution should integrate in their daily work environment
Steel manufacturing companies (customers)	Primary	Optimizing machine output	Moderate, the solution should trigger or attract them. Also, more demand means more reason to develop it.
Operators	Secondary	Ensure smooth production and get updates on machine status	Low-moderate, as they are not directly involved but the solutions might have effect on their work
ICT-developers	Secondary	Developing a working application	Moderate-high, they do contribute to the technical development of the solution, but are not involved and interested in the goal of the application.

Regulatory authorities	Secondary	Ensure compliance with the regulations, as much data is collected and used	Low, as they only provide guidance in following the rules and guidelines.
Data Analyst	Tertiary	Collecting and analyzing machine data	Low-moderate, as I am not going to use real-time data, but might use historical data.
Sales managers	Tertiary	Present and sell the solution to customers	Low, they have no direct influence on the project, but try to find out what customers want and deliver that information to people that can realize that.

Table 4.1. Stakeholder analysis

4.1.2 Influence/Interest Grid

Furthermore, an influence-interest grid is made to get insights in on how to engage each stakeholder. This grid is divided into four categories, which will correspond to the stakeholder based on the combination of the impact and influence of this stakeholder (table 4.2).

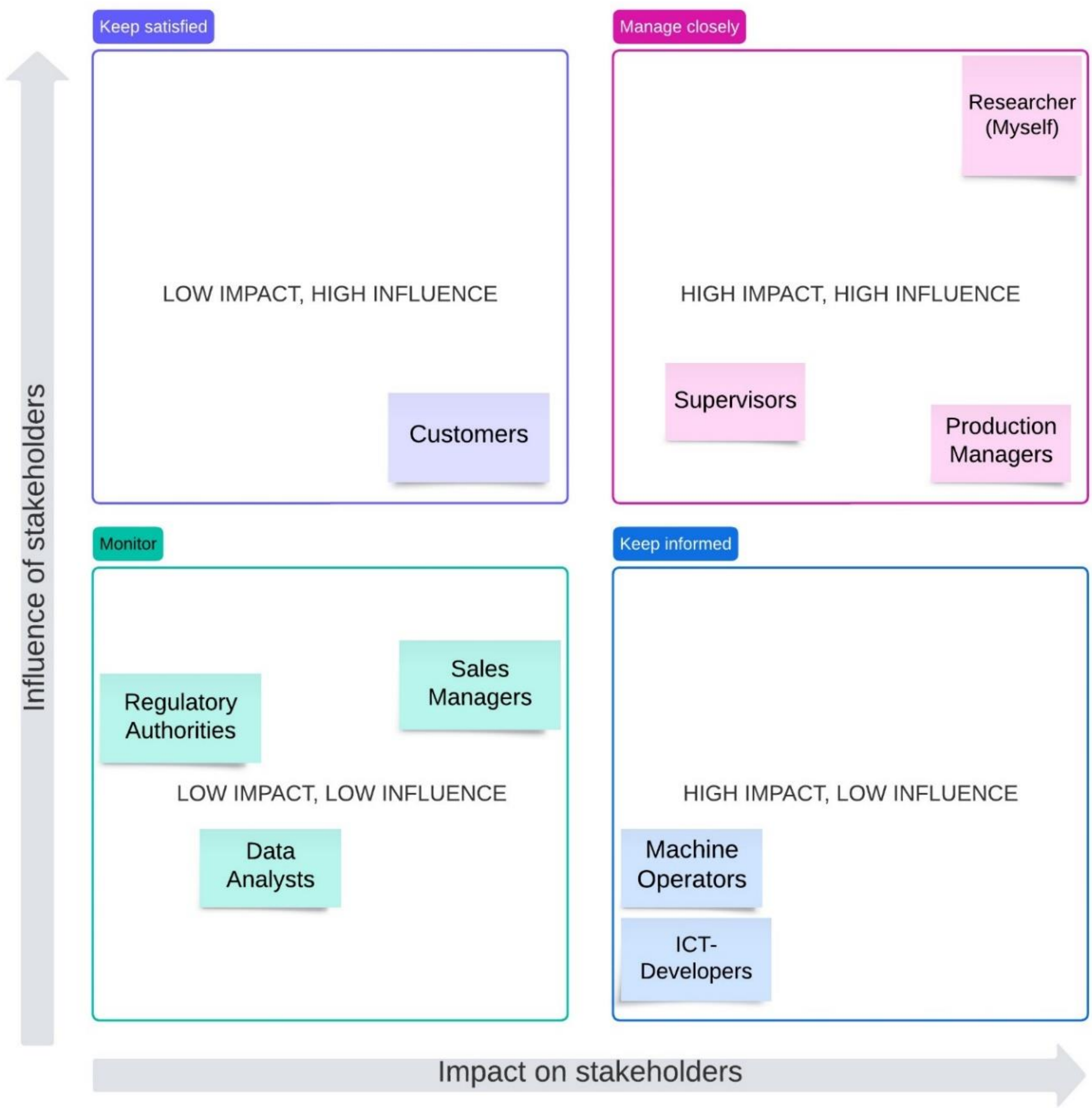


Table 4.2. Influence/impact grid for stakeholders

4.1.2 Production Manager

From this table and grid, a conclusion can be drawn that the production managers are the most important stakeholders in this project, as they have a high impact and a high influence on the project. That is why it is important to know what a production manager is.
A project manager is a professional who keeps the overview of a production process. This includes planning, solving problems and keeping the production up and running. It is his task to ensure that the production that is scheduled is achieved. Most of the times, the production manager is located in or near the hall where the production takes place, so operators can easily reach him, and vice versa. They are also interested in optimizing the output as much as possible, and to guide the operators in this. This might be difficult sometimes, as operators have different goals than a production manager, and might not want to work that hard [35].

4.1.3 Conclusion

As mentioned above, the production managers are the most important stakeholders. Customers also have a high influence, as the requirements should fulfil their wishes. However, the impact is low, as the solution might not be applicable to them.
Moving on to the keep informed category, where the machine operators and ICT-developers are. They do not have a great influence on the project, as they are not the target audience. Although, the solution might have impact on their work. For operators, the work structure and tools they use might change. ICT-developers should only focus on designing the application, and thus have a low influence but still a high impact.
In the monitoring section, the data analysts, regulatory authorities and sales managers can be found. These stakeholders have a low influence on the project, and the solution has a low impact on them. They are more in the background, to collect data, comply with the rules, and to promote and sell the solution to customers.

4.2 Brainstorming

To identify potential technologies and concepts on increasing the uptime, and to determine the requirements of the solution, an individual and a group brainstorming session are conducted. What the goal of the sessions are and what method will be used, is explained in section 3.2. In the end, a few concepts are defined and tested with prototypes, to choose the final concept which will be further specified and developed into a final design.

4.2.1 Individual brainstorm

First of all, as many technologies as possible are come up with that might apply to the environment of the production manager, or technologies that can present data from one machine in any way. This method ensures that almost all possible options will be addressed.

Even when the technology is not feasible for this project or the ideas, parts of it might be useful to implement in the solution.

Technologies

Dashboard: Screen/interface/application running on the production manager's laptop
Phone/Watch/interactive bracelet: Tangible, smart wearable that might vibrate/make sounds/give notifications
LEDs: Lights on the shop floor or at the office
Gamification: Create a gamified system out of the production process, with a competition or a gamified production goal for example
Voice Assistant: Assistant which provides relevant machine data and advice, and can be interacted with
Collaborative whiteboard: Used for brainstorming, getting multiple perspectives, writing down remarks or particularities
Drones: Fly through the shopfloor, and gather relevant information with a camera
AI Chatbot: Questions and advice can be asked to this bot about the machine
Remote monitoring: Control the machines/production process remotely
Cobots: Collaborative robots that can assist the operators in automating simple tasks to save time
VR/AR: Virtual/Augmented Reality can be used for machine simulations or digital instructions
Digital twin: Virtual replica of a machine to simulate production processes

Selection

Not all technologies are feasible or applicable, because they are not able to present actionable feedback to the production manager, they don't use any data from EVI or the ideas cannot be integrated in that specific technology. For example, an automated weekly report cannot be shown by LEDs. That's why a selection is made of the ones that potentially can be used in the final prototype. This includes the dashboard, the phone/watch/interactive bracelet, and gamification. The selection is based on how the technologies can be implemented in the production manager's environment, and how the technology might present data and actionable feedback to the production manager.
Based on those technologies, Lo-Fi prototypes will be made to test and evaluate them, and to see how they might be implemented into the final prototype.

To further specify the technologies, the brainstorming session will be split into two parts, where the input of the production manager and the output of the design will be determined in the table below. Furthermore, the advantages and disadvantages will be roughly listed.

Technology/ Method	Input production manager	Output of the design	(Dis)advantages
Dashboard application	What data the production manager wants to see, and whether he applied the advice or not	Showing and comparing data from the past to advise about the future	+ Quick overview of output + Easy to compare with optimal output + Learning effect, as each week will be better (Ideally) - Can't bring your laptop easily to shop floor
Smart wearable or phone	What data/machine the production manager/operator wants to get notified about	Sounds/vibrations/lights to notify the production manager (live data)	+ Live notifications about machine output + Easy to use in the shop floor - Hard to present data on a small screen
Gamification	Production goals per week	Presenting the goal in a gamified way, giving rewards etc. when achieved	+ Engaging to achieve production goals + More fun - Hard to determine what works for everyone, and if it really catches on

Table 4.3. Input-output model per technology

4.2.2 Group brainstorm

To evaluate the chosen technologies and to see how they can be transformed into concepts, a group brainstorm session is done.

At the start of this brainstorm session, the role storming technique will be explained. In this session, it will be the role of the production manager who wants to optimize the machine output, as that is our target audience. After that, the three ideas (Prescriptive maintenance, automated weekly report, Root Cause Analysis) will be presented by means of explanation and Lo-Fi paper prototyping.

When the session starts, each concept idea will be evaluated, and questions about requirements, features and the relevance of the concept and the technology in relation to the project will be discussed. These questions, the Lo-Fi prototypes and the results can be found in Appendix C. After that, the preliminary requirements are set up and based on that, concepts will be specified and prototypes will be made for the user test of the concepts.

4.2.2.1 Prescriptive maintenance

Requirements & features

> Smooth communication between production managers and operators, to pass on information on what action to take

> Give warnings or alerts on beforehand when action needs to be taken

> Show the impact of the action, so the situation before and after

> Reset the values when a tool is replaced for example

> Put in current machine settings to present corresponding RUL, as for example a higher rpm decreases the RUL

Pros

+ Decreases unexpected machine breakdowns → operator has more time to do other work

+ Resolves issues before they become critical problems

+ Maintenance can be planned better to work more efficiently

+ Quality & performance increases when tool wear is taken into account

+ Look forward to prepare for upcoming production process (For example, add a tool to the machine manually)

+ Reduce costs

+ Concrete, specific feedback can be given

Cons

- Hard to get specific, accurate data on Remaining Useful Life (RUL)

4.2.2.2 Automated weekly report

Requirements & features

> Show actual data about the output compared to the average output, take action when actual output is significantly lower

> Show where the most profit can be achieved, to prevent trying to improve something that is almost optimal

> Show the Key Performance Indicators (KPIs)

> Give useful tips that work, otherwise they will be ignored

Pros

+ Quick overview of how you produced last week

+ A weekly update on your production output can serve as a reminder, that you keep thinking about it and try to optimize it

+ Easy to compare output with other weeks or the optimal output

+ Recommendations on how to increase your uptime

Cons

- Can be difficult to provide specific feedback if the underlying cause is not fully defined or known

- Overview of production output is already in EVI

4.2.2.3 Root Cause Analysis

> Give an overview of live incoming issues

> Show the impact of the issues on the uptime

> Show the most recurrent issues in the last period of time

> Provide information on what the root causes are of the problems, and a few options on how they might be solved

Pros

+ Resolve problems faster when the cause is known → Less maintenance

+ Frequently occurring problems can be detected and action can be taken to fix them

Cons

- Lots of overlap with the automated weekly report, the difference is that the focus lies in the weekly report on the output, and with the Root Cause Analysis on technical issues
- Is more a technical problem where more research is needed
- The solution might be more a tool to find the root cause than a tool that tells the production manager/operator how to fix it

4.3 Preliminary requirements

To translate these ideas into actual concepts, a few requirements need to be set up which should be fulfilled by the concepts. These requirements are based on the two brainstorm sessions and the interviews that have been conducted:

- The production manager must be empowered by the design to optimize the machine output
- The design must integrate seamlessly into the production manager's working environment
- The design must provide actionable feedback that, when applied, optimizes the machine output
- The production manager should be able to customize options within the design to provide flexibility to their preferences
- The design should include continuous operation
- The design should present changes in results to the production manager
- The design should serve as an extension of EVI, ideally by using its data
- The design should be informed about if the actionable feedback is executed, and update the system based on that

- When the actionable feedback should be executed by someone else, for example the operator, the communication should go smoothly and without effort between the operator and the production manager

4.4 Developed concepts

Based on these brainstorm sessions and the preliminary requirements, two main concepts are defined. Prototypes of these concepts will be made, whereafter they will be tested and evaluated to get a final decision, and to continue with the specification phase. The paper prototypes used in the group brainstorm session that visualize these concepts can be found in appendix C. First, the current situation will be explained, whereafter information is provided on how the concept can improve the current situation. Then, the concept itself is explained.

4.4.1 Concept #1 – Prescriptive maintenance dashboard

Current situation

Currently, information on the RUL is presented in VACAM, the software of the Voortman machines. However, as can be seen in figure 21, the max tool life can be changed easily. This, because the value is not supported by any research, it is a rough indication on what the maximum tool life is. When this value is exceeded, a notification will be given in VACAM. The operator, if he sees the notification, can plan maintenance to change the tool. However, when the operator does not notice the warning, the machine continues producing till the drill breaks, which may cause much more problems than replacing the tool on time. Furthermore, information on the machine settings is presented, but they are not taken into account when calculating the tool life. This means that the value of 30000 mm is a very

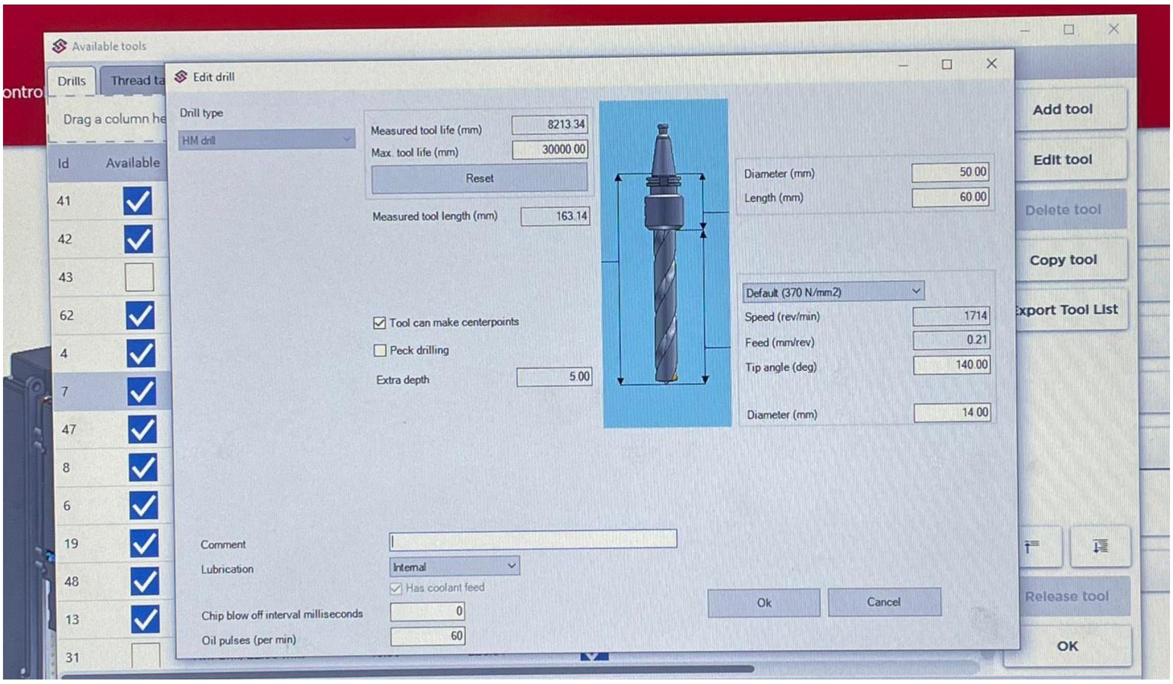


Figure 4.1. Tool life measurement in VACAM

rough estimation, and that the tools are replaced too early most of the time, leading to an increase in the costs.

Benefit

The first concept is about prescriptive maintenance, as (unplanned) maintenance is one of the main reasons of machine downtime. Giving information on beforehand on the RUL of tools by predicting when maintenance is needed or when the tool is worn out, will lead to a more efficient planning of the maintenance, leading to an increase in the uptime. Providing actionable feedback towards the production manager by telling him what to do (prescriptive) is the next step, and helps to prevent unplanned machine breakdowns. This way, the operator has also more time to do other work. Furthermore, by replacing machine parts or tools in time, issues will be resolved before they turn into critical problems. During this replacement, tools that need to be put in manually can also be added, making it more efficient.

Idea

The idea is to have a dashboard on the laptop of the production manager, where real-time information about the RUL of the tools of one machine is presented (figure 4.2). This will be done in millimetres, as that gives the most accurate view. Measuring it in holes vary in diameter and depth, which makes the data much less accurate to use. The system will keep track of the amount of millimetres that a drill bit can drill or a saw blade can saw before it is worn out or breaks, and actionable feedback is presented based on that data by alerting the production manager with notifications. This way, the production manager does not have to look to this dashboard all day waiting for actionable feedback. When a notification is coming in, the production manager directly sees what is going on and what tool need to be replaced to prevent unplanned machine breakdowns. He is not going to change the tool itself, as that does not make sense and it is a job for the machine operators. This means that the production manager should be able to notify the operator easily to tell him that a certain tool needs to be replaced before the next part will be processed. The operator could receive this message on a phone, smartwatch or an interactive bracelet for example. After replacing, the operator should send a verification message back to the production manager to ensure that the system will update and that the production can continue.

When providing information about the RUL, the system should take the machine settings into account, and the production manager should be able to change those settings. When the current machine settings are filled in, the system gives information on the actual situation. However, when these settings are changed, the RUL changes too. If the performance of the machine is lowered in the settings to run more economically, for example at night, the RUL increases. This means that when taking the machine settings into account, more accurate feedback and information can be provided, to get the most out of the tools and the machine. This concept also looks forward, to see what is coming up and how to prepare for it, while the other concept is more a descriptive and diagnostic approach, and is more about what happened why.

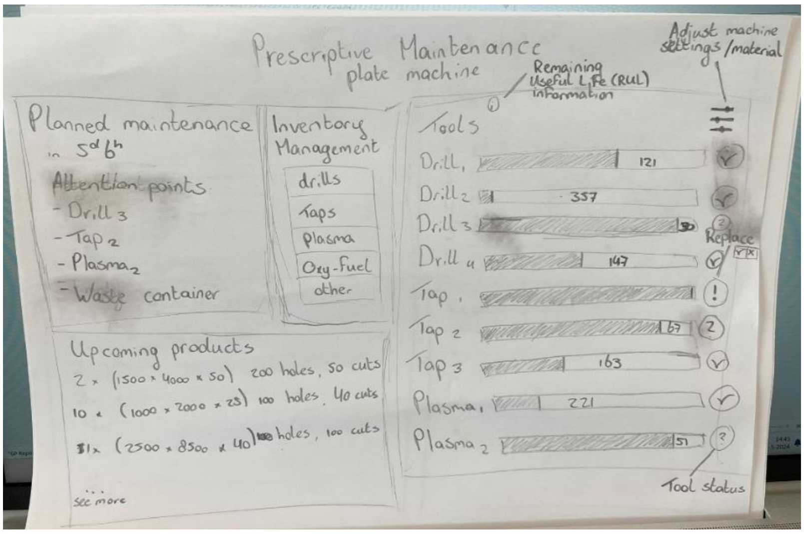


Figure 4.2. Prescriptive maintenance paper prototype

4.4.2 Concept #2 – Automated weekly report + Root Cause Analysis

Current situation

For now, there is not yet a kind of weekly report that summarizes the production of the past week. However, within EVI, there is the option to filter on machines and period of time, where the performance within that time period can be seen. This won't summarize the results, but just puts them under each other. Furthermore, there is no advice or actionable feedback presented to improve that performance.

Root Cause Analysis is also not yet presented in EVI. There is data available on the reasons of the downtime, but it is not specific enough to know the underlying cause of it. This means that there is not yet a feature that can tell exactly what the reason of the safety error was for example, and how to optimize or solve it.

Benefit

The second concept focuses on the automated weekly report, where the production manager receives a summary of the machine performance at the end of each week. This report gives a quick overview of the Key Performance Indicators (KPIs) of one machine. This is for example the uptime, the amount of operations or the tonnage produced in that week. By receiving this report every week, trends and particularities can be identified, for example to see that the uptime was below average last week. To provide actionable feedback based on this data, the cause and the impact of the issues that decrease the performance should be known. This way, tailored recommendations can be presented to the production manager to resolve those issues.

Idea

A paper prototype on how the report would roughly look like can be found in figure 21. An interactive report that will be delivered automatically to the production manager at a time he wants to, every Friday afternoon for example. First, the actual performance is compared to the optimal performance (based on machine availability), to see how close to optimal the production is. What data is shown in this graph should be the choice of the production manager, and he should be able to easily change this. Furthermore, the maintenance actions in that week are presented, to see what maintenance is conducted when, and how long that took. This way, changes in the actual performance can be explained better, as a lot of maintenance in one week causes a reduction in the uptime and output of the machine, which can be seen back in the graph. Furthermore, to identify the reasons why the performance is not optimal or below average, a downtime analysis will be implemented in the report. In this analysis, the reasons that contribute the most to the downtime are listed, from high to low. To provide accurate, useful recommendations on how to optimize the machine performance, the underlying cause should be known. Therefore, Root Cause Analysis should be executed. This way, when the cause of a problem is known, actionable feedback can be provided on how to solve that problem. Furthermore, frequently occurring problems can be filtered out and solved to prevent them from happening in the future. By receiving this report each week and applying the actionable feedback, the performance will keep coming closer to optimal, which means that this report leads to continuous improvement.

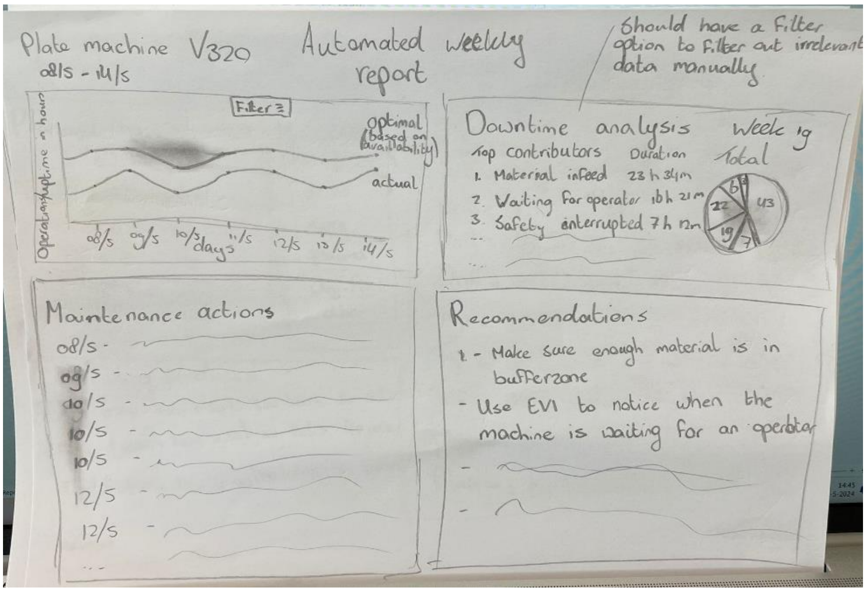


Figure 4.3. Automated weekly report paper prototype

4.5 Conclusion

In the ideation phase, the transformation from the background research to potential solutions to the problem took place. First, the stakeholder analysis was set up to have an overview of who is involved or affected, and what influence they have on the project. Secondly, an individual brainstorming session was executed, to come up with possible technologies that might be suitable for the solution. To get more insights in the requirements and the (dis)advantages of the four ideas, a group brainstorming session was held with 5 people, including the researcher. Based on these brainstorm sessions and the background research, the preliminary requirements the solution should fulfil were set up. In the end, two concepts are defined on the basis of these requirements, which may serve as potential solutions to the problem. Therefore, a decision has to be made to continue with the specification phase of one final concept. This is done by comparing them to each other and to the preliminary requirements.

In the prescriptive maintenance dashboard, real-time data is presented to the production manager. The advantage is that actionable feedback can be applied directly, which leads to continuous operation. This is not the case in the weekly report, as there a summary of the performance of last week and recommendations for next week are given.

Furthermore, it is hard to provide specific, actionable feedback in the weekly report, as the underlying cause why the uptime is below average for example is not fully defined most of the time, as this information is not available in the weekly report. This requires a Root Cause Analysis system, which is a much more technical solution and not within the scope of this project. On the other hand, specific, actionable feedback can be given in the prescriptive maintenance dashboard. By providing real-time information about the current RUL of tools and machine parts, advice or warnings can be given when these tools are worn out and ready for replacement. The production manager on his turn can then notify the operator to execute the action, preventing unplanned maintenance.

Another difference between the two concepts is that with prescriptive maintenance, the machine settings are taken into account. This way, the production manager receives accurate data based on the machine settings he puts in, which in the end will lead to more efficient tool use which reduces the maintenance costs. For example, at the end of the day, when the production manager prepares the machine for the coming night, he might want to decrease the performance of the machine as there is time enough to finish the parts before the next morning. This way, the machine runs more economically, which means that the RUL of tools increases. For example, when a drill bit is running at an rpm of 800, the amount of metres it can drill before it breaks is 15. When decreasing the rpm to 500, the drill bit can drill 20 metres before it breaks. This ensures efficient use of the tools, and that you get the most out of it. In the automated weekly report, the machine settings are not taken into account. Advice may be given on changing the settings, but once the machine settings are optimal, there is no need to give advice on that, so there is no continuous operation.
This means that based on the comparison of the two concepts with each other and the preliminary requirements, the prescriptive maintenance dashboard is chosen as the final

concept. In the next phase, this concept will be further specified to prepare for the realization phase.

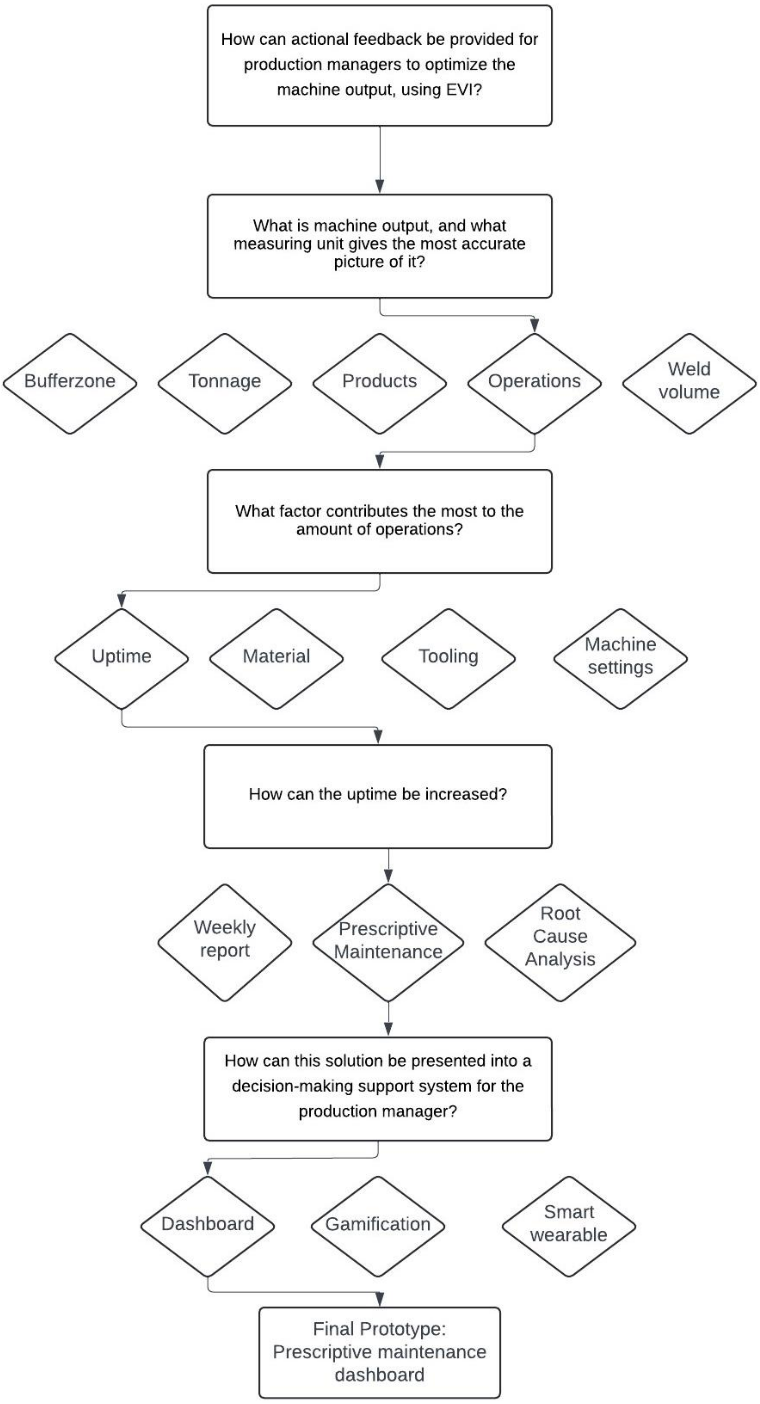


Figure 4.4. Updated GP roadmap

Chapter 5 – Specification

In the Creative Technology design process, the specification phase is the bridge between the concept idea and the realisation of it. The background research and the ideation phase are fundamental to start specifying and realizing the concept idea. In this phase, a user scenario is set up, the (non)functional requirements will be defined, and the functional architecture is established. This, to give a better view on how the solution will be integrated in the production manager's environment, and how it will be used. Furthermore, Lo-Fi prototypes will be made to conduct user tests in the evaluation phase.

5.1 User scenario

Setting up a user scenario helps to get a better understanding of the user needs as the implementation of the solution will be seen from the users perspective, in this case the production manager and the operator. Furthermore, the effectiveness of and the interaction with the solution is worked out, to ensure that the requirements are fulfilled and that the prototype works the way it should. First, the personas have to be defined and what their goals and needs are. Afterward, the scenario will be set up to provide a better view of the implementation and interaction with the concept. A quick sketch is made from the scenario, where the numbers at the sub-headers can be found back in figure 5.1 below the scenario. This scenario is about the implementation of the prescriptive maintenance dashboard in a steel processing company. In this dashboard, real-time information is presented about upcoming parts the machine has to process and the RUL of different tools and machine parts. Based on this information, alerts and warnings will be given to the production manager when action needs to be taken. The production manager then can choose to notify the operator about this, to replace a certain tool for example. The operator will validate that by sending a message back to the production manager, and the system will be updated.

5.1.1 Personas

In this user scenario there are two personas, which are the production manager and the operator. Their work environment and goals are described below, where the production manager is the most important one as he is the target user of the developed concept.

Production manager Peter: During the day, the production manager is most of the time in his office, which is located near the shop floor so he can see the machines and the operators working. His job is to plan and keep track of the production, and his goal (most of the time) is to have as much machine output as possible to ensure that the production goals scheduled for that week will be achieved. Furthermore, he may assist machine operators in their work by providing resources and making sure issues will be solved quickly, so production can continue. Currently, communication between production managers and operators is mostly face-to-face, or by calling them on the phone. In this user scenario, the production manager is called Peter.

Operator Bert: The operator is a person that controls the machine on the shop floor. He makes sure that the machine keeps running and that the parts and projects planned will be processed in time. This includes material infeed and outfeed, maintenance and manual checks. However, in contrast to the production manager, the operator mostly doesn't care that much if the planning goals are achieved. Firstly, because he does not have insight and influence on this planning, and secondly, he doesn't want to work too hard or put too much effort in it to achieve the goals of the production manager, as he just does his job and that's it. This may lead to frustration between the two when the planning is not finished. In this user scenario, the operator is called Bert.

5.1.2 Scenario

Start of the day (1)

It's Friday morning, Peter goes to his office, starts up his laptop and logs into the prescriptive maintenance dashboard of the plate machine V310. No warnings or alerts, so production can continue as usual.

On the same morning, Bert starts on the shop floor, by removing the processed parts from last night, and prepares the machine for production by inserting a project and by loading up the machine with steel plates needed for that project. Furthermore, he starts up the application where he will receive notifications on from Peter, and turns on the sound and vibration.

Figure 5.1 Production manager's workplace

Dashboard warning (2)

As the morning passes by, no particularities occurred. Till 11:47, when Peter gets a notification on the dashboard: “Attention: Drill #4 – RUL: 15 cm. Maintenance required soon.” He clicks on it, the notification expands and a more detailed analysis of the issue is presented:

- **Issue:** Drill #4 is approaching the end of its operational life, 15 centimetres left to drill.
- **Recommended action:** Notify operator about the issue and replace the tool before the next project.
- **Impact if delayed:** The drill bit might break, causing unplanned downtime and affecting production schedules.

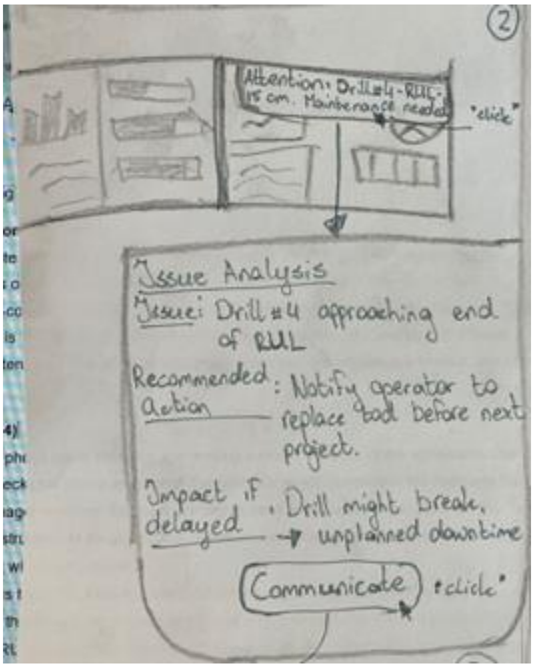


Figure 5.2 Dashboard warning

Communication with operator (3)

To communicate the issue and recommended action with Bert, Peter clicks on the “Communicate” button at the bottom of the notification screen. An automatic, pre-compiled template appears which is filled in by the production manager: “The RUL of drill #4 is 15 centimetres, and should be replaced before the next project. Please schedule maintenance.” Peter checks if the message is correct, and hits “Send.”

Figure 5.3 Communication with operator

Action taken (4)

Bert's phone starts vibrating and making a sound because of the notification that came in. He checks his phone and opens the notification, which contains the message Peter sent him. Bert sends back a check mark and confirms that he has read the instruction. In the production schedule, he adds the maintenance action before the next project will be processed.

When the time is there, Bert replaces drill #4 as planned. He updates Peter about this through his phone, and the system will mark the maintenance action as complete. The RUL of drill #4 will reset, and Peter receives a notification: "Maintenance action complete: Drill #4 is replaced. Updated RUL – 10 metres."

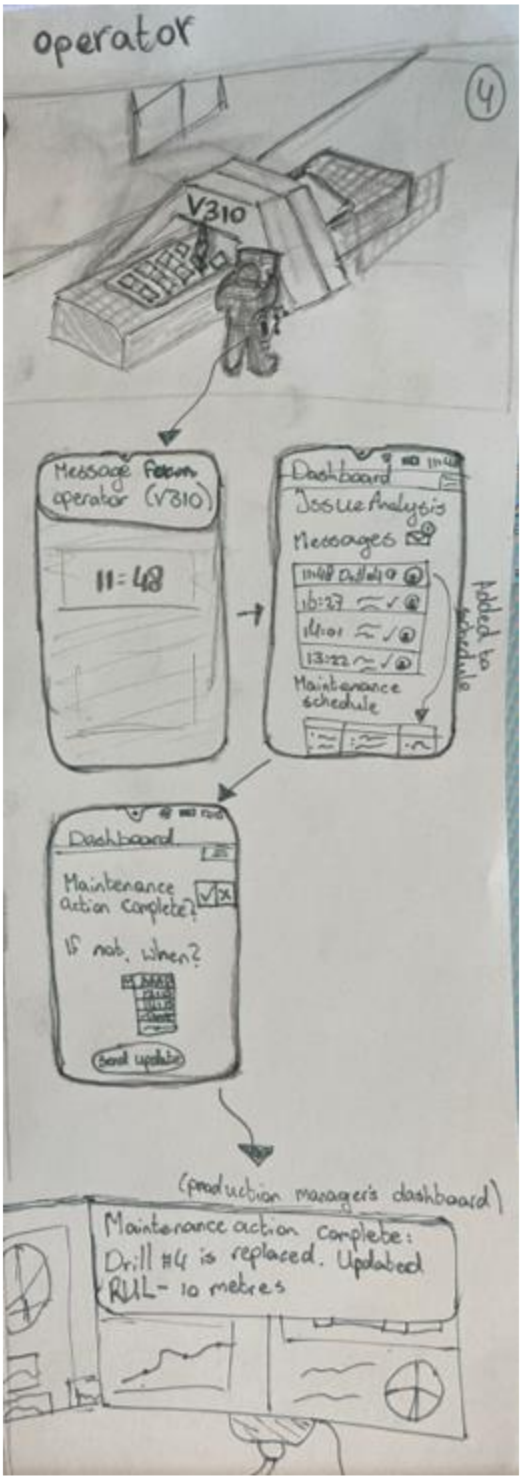


Figure 5.4 Action executed by operator

5.2 Functional system architecture

To outline the workflow and to illustrate how the production manager, the machine and the operator interact with the prescriptive maintenance dashboard, an activity diagram has been set up in the figure below.

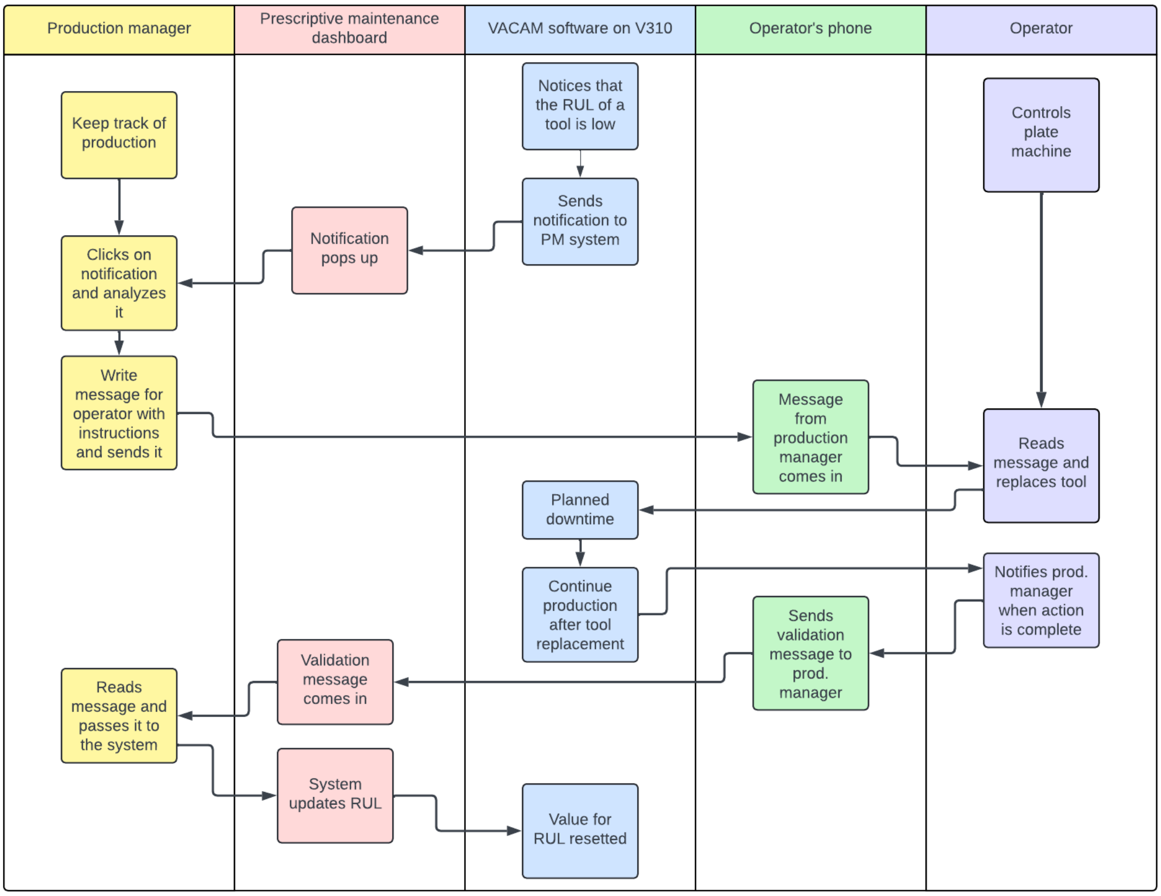


Figure 5.5. Activity diagram

This activity diagram shows the sequence of the interactions between the production manager, the prescriptive maintenance dashboard, the software that runs on the machine, the operator's phone and the operator. It displays the flow when the dashboard is implemented, and when a tool is nearing the end of its operational life. At the top, the software on the V310 (blue column) notices that the RUL is almost 0. By following the arrows, the interactions between the components become visible, till the tool is replaced and the RUL value has been reset.
This diagram only shows the interactions when the RUL of a tool is low. As this contains actionable feedback, the design is mostly focused on that part and that is why the activity diagram only includes the interactions that happen when a tool needs to be replaced.

5.3 Updated requirements

After choosing the final concept idea, the requirements should be updated. This will include the MoSCoW method, where the requirements will be categorized based on their priority. Furthermore, they will be divided into functional and non-functional requirements.

5.3.1 Functional requirements

The functional requirements specify the system should do and describe specific behaviour and functions of the system. This includes the **what** system's features, interactions and requirements. The requirements are addressed for the production manager, unless otherwise stated in the requirement itself. In this project, the solution:

Must

- Must show data on the RUL (Remaining Useful Life) of tools and machine parts
- Must provide recommendations on what to do based on that data
- Must generate warnings or alerts to the production manager when tools are nearing the end of the RUL
- Must reset the RUL when a component is replaced
- Must deliver notifications to the operator without delay
- Must notify the operator by vibration and sound alerts
- Must allow operators to confirm task completion back to production manager
- Must show improvements on maintenance time based on initial state
- Must be compatible on various devices, such as a laptop and a phone
- Must include continuous operation

Should

- Should allow to edit messages before sending them
- Should take into account the production planning, and if it can be theoretically achieved with the current tools
- Should include details in the notification, such as the issue, the recommended action and the impact when action is not taken
- Should include the option to change the machine settings and see the corresponding RUL
- Should show a tool inventory with the corresponding RUL and where they are located
- Should work on various operating systems, such as Windows, macOS and Linux
- Should be designed in an interface design application, to focus on the presentation of the data rather than the technical aspects of collecting the data
- Should give an overview of the planned maintenance, and if it's done or not

- Should possibly be integrated in EVI, when the data is available

Could

- Could provide reports that summarize the maintenance activities
- Could present advice on the machine settings by letting the system know how you want to produce
- Could show historical data on tool usage
- Could give an overview of the average tool life to give more accurate information about the RUL
- Could support multiple languages as some people are more comfortable with another language

Won't

- Won't show data of multiple machines
- Won't use AI to provide recommendations

5.3.2 Non-functional requirements

The non-functional requirements focus more on the overall qualities of the system. It specifies **how** the system should perform its functions, and needs user-testing for validations. Therefore, the solution:

Must

- Must equip the production manager to increase the uptime of the machine
- Must not distract the operator so it creates dangerous situations
- Must not increase the cognitive load of the operator
- Must integrate seamlessly into the production manager's and operator's work environment
- Must comply with data and security rules
- Must be intuitive for the user

Should

- Should be designed in a way that updates or features can be added without major redesign
- Should have an easy-to-navigate user interface

Could

- Could make the machine more sustainable by providing data on energy consumption

Won't

- Won't use real-time data to provide actionable feedback
- Won't include machine learning to identify data trends

5.4 Technologies

Figma

To realize the prescriptive maintenance dashboard, the application Figma is used [36]. Figma is a web-application for interface design. It can be used to build clickable prototypes, such as apps, websites and dashboards. As Voortman also uses Figma to design their interfaces, a premium subscription was made available for me, which means that I can use more features to make the design. Furthermore, someone who graduated on designing a Figma application for welders helped me get started with it by explaining the most important things. Next to that, I have watched some tutorials and clicked around Figma myself, to get familiar with the application.

5.5 Tool RUL information

To get more knowledge about the RUL of tools and the machines at Voortman, an interview was conducted with the Product Manager Tooling. He is an expert in the parts & consumables field, and his job is to see where improvements can be made and how. He provided more information about the factors that influence the RUL, and what happens when the tool is not replaced in time.

The average distance a drill can last in the V310 is about 6 metres, but as can be seen in figure 21, the maximum tool life is set to 3000 millimetres, which equals 3 metres. Here, a lot of profit can be made when analysing how long a tool actually lasts. In other, newer machines, the drill distance can go up to 40 metres due to a huge increase in stability, as vibrations cause a lot of tool wear.

For plasma tools on the V310, the RUL is 500 metres or 500 start-stops. If either value is reached, the part should be replaced. However, the parts inside a plasma tool have different RULs, so it's not possible to change the whole tool. This will change in the future, where the plasma tool does not consist of different parts, but it's merged together in a cartridge.

For milling tools, the RUL can vary a lot. For now, the RUL is about 1-1.5 hour of processing. To improve the tool use and get the most out of the tools, research and tests should be done to theoretically find out what the real RUL of a tool is. That way, actionable feedback will be even more accurate, and maintenance costs will decrease.

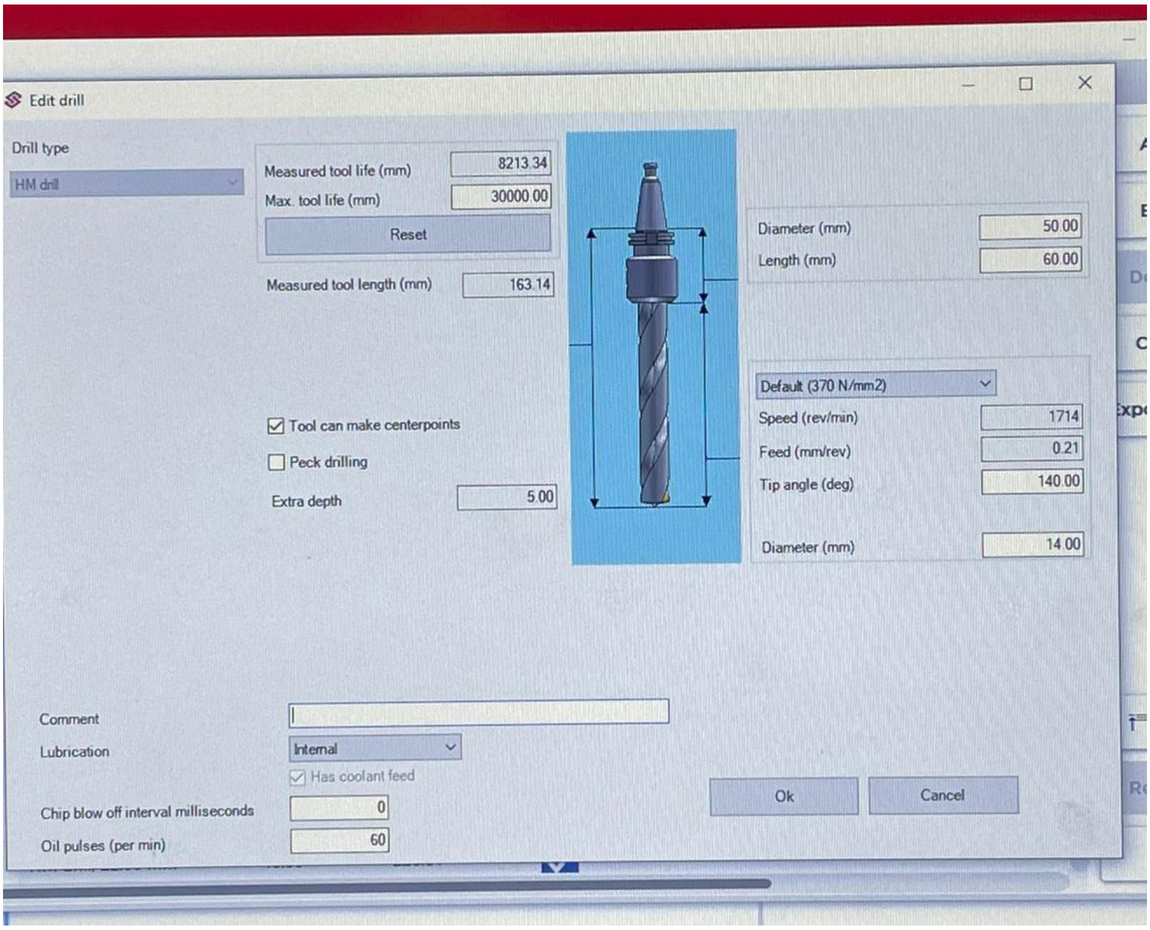


Figure 5.6 Tool life measurement in VACAM

5.6 Conclusion

Based on the activity diagram and the (non-)functional requirements, a clear concept idea is established which is ready for the realization phase. The activity diagram along with the user scenario showed more about how the concept will be implemented, and how the users and system interact with each other. The requirements identify all the features and needs the design should comply to, to ensure having a working prototype at the end. Furthermore, the interview gave more insights into RUL of tools, and what factors have an influence on that.

Chapter 6 – Realization

In this chapter, the third phase of the Creative Technology design cycle will be executed, the realization phase. In this phase, sketches and Lo-Fi prototypes of the design are made and evaluated to get a clear view on how the final design should look like. Then, while designing the concept in Figma, it will be constantly evaluated to prevent the need for major changes in the end. When the design is finished, it is ready for the evaluation phase.

6.1 Lo-Fi prototyping

Before starting in Figma, a Lo-Fi paper prototypes of the dashboard for the production manager and the phone for the operator have been made, which can be seen in figure 6.1 – 6.3. These prototypes are based on the requirements the design should fulfil. Furthermore, together with the user scenario, it gives a clear explanation of how the design might look like and how the implementation will be. To get feedback on this prototype, an evaluation is done by a production manager of Voortman. This feedback should mostly be implemented in the design, as he is part of the target audience. Furthermore, he has a lot of contact with the operators, so he also knows what he can expect from them when implementing this design.

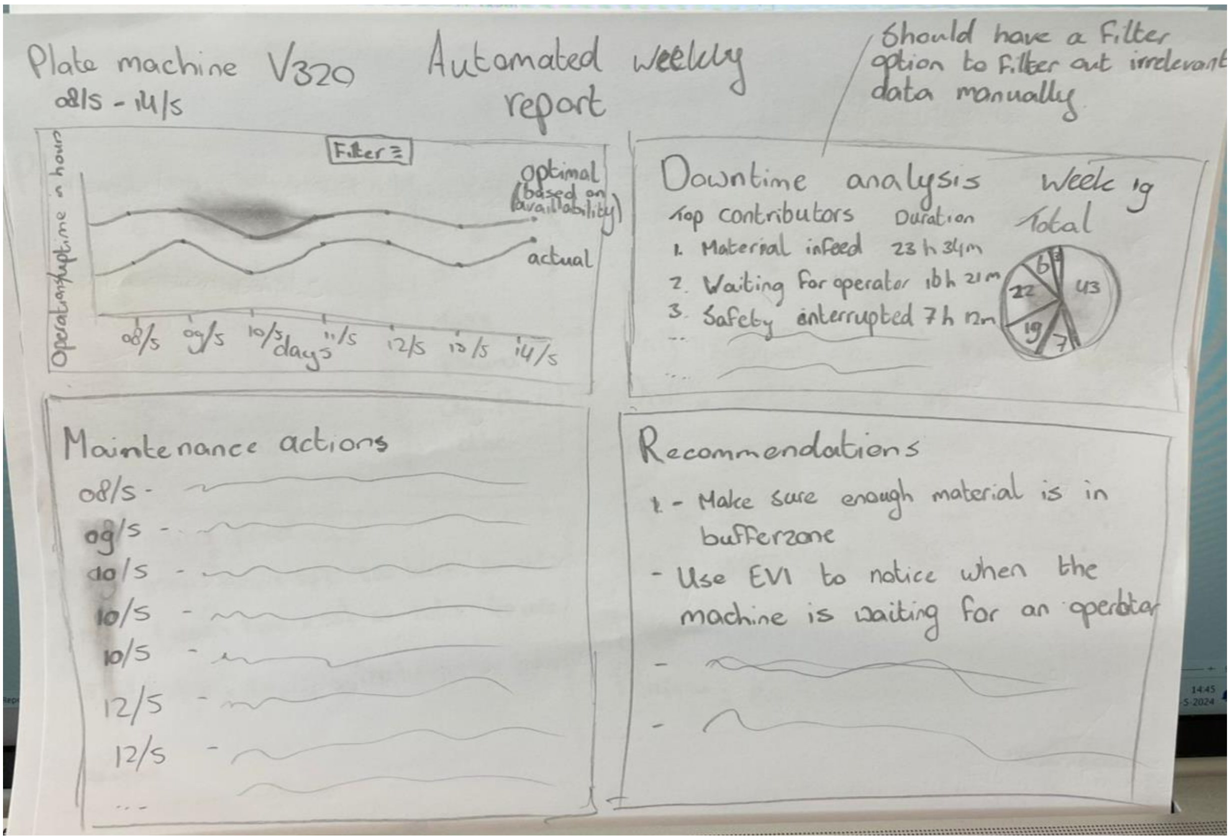


Figure 6.1 Automated weekly report

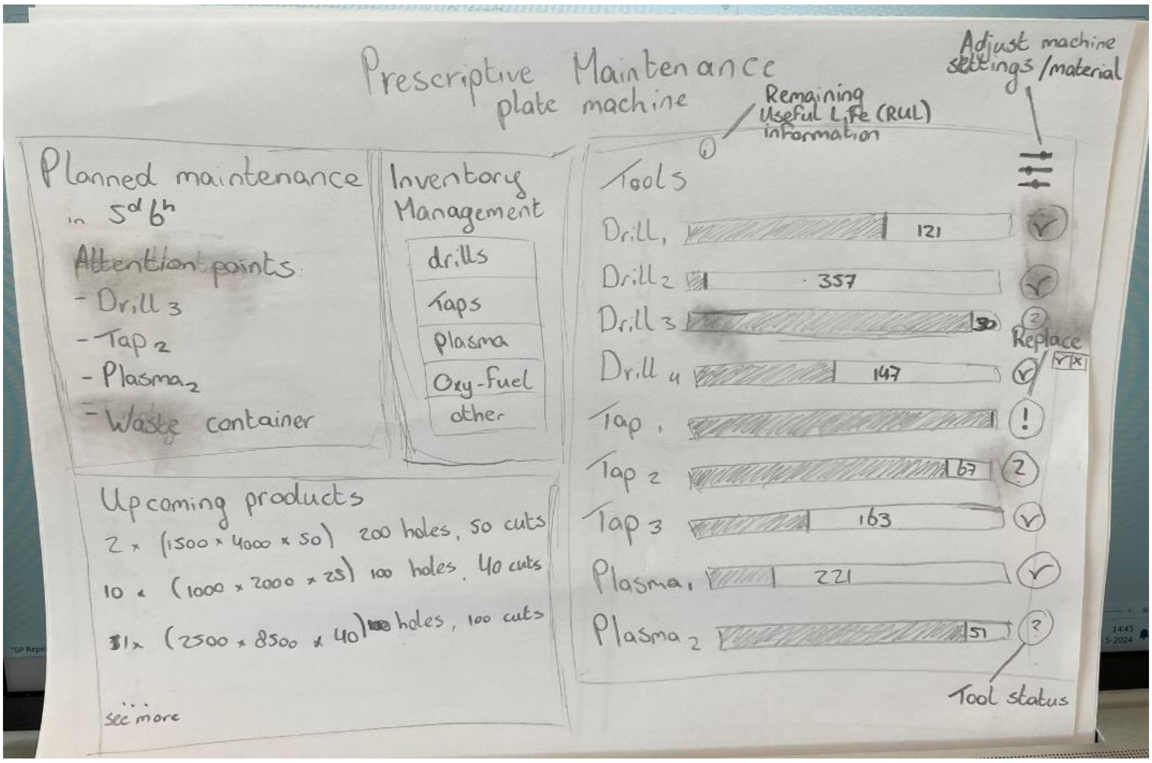


Figure 6.2 Prescriptive maintenance

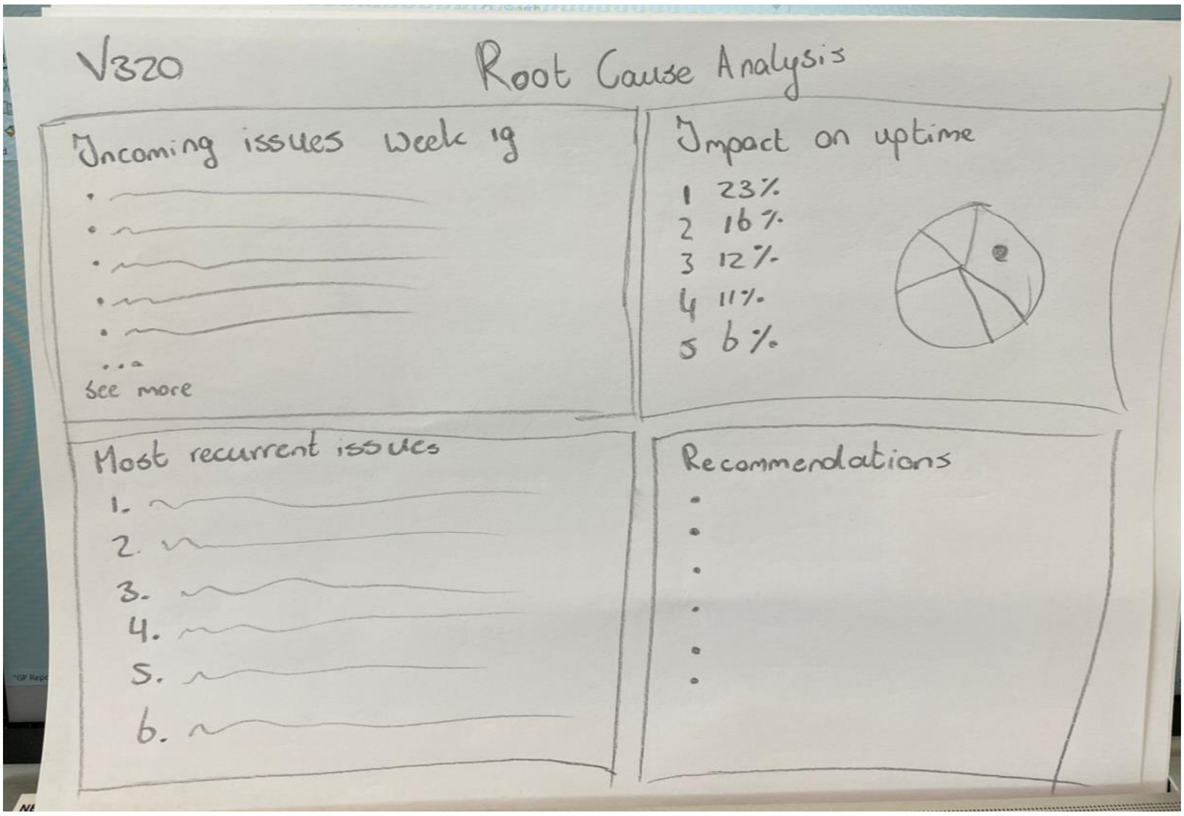


Figure 6.3 Root Cause Analysis

At the start, the idea behind the sketches were explained, and what the data means. Furthermore, he 'interacted' with the prototype, by changing the sketches when he clicks on a button for example. This gives a better visualization of how it should look like. Afterwards, a few questions were asked about the design, and about features that are unnecessary or missing. The first thing he said was that currently, EVI is a monitoring application. It only shows data, but does not tell you what to do on how to increase the performance for example. This makes EVI unattractive for operators, because they might get the feeling that they are monitored the whole time. With this prescriptive maintenance dashboard, EVI will become a useful tool for production managers and operators, as it presents advice to them on what action to take.
When it comes to maintenance, especially tool wear, it currently is handled based on the instinct and expertise of the operator. By listening to the machine and looking at the steel chips, the operator can determine if a tool is almost at its operational life. However, this is not really accurate, and when the operator is not paying attention to the machine, or is busy with something else, he might not notice it.
His first impression was good, and he thought that the dashboard has much potential to serve as an extension to EVI, and that it will decrease the downtime and the maintenance costs. He liked the real-time RUL data from the tools, and that it also takes into account the production planning. It also shows on beforehand whether a project is theoretically feasible based on the RULs of the tools that execute the project. This way, the production manager and operator can prepare for every project, and that the machine will not break down unexpectedly, which is especially helpful when putting on the night plate. The night plate is a plate that they will put on the machine at night, when there is nobody at the factory. This plate needs a lot of processing, so a lot of holes and cuts etcetera, which can take up 4-5 hours easily. When a tool breaks in this process, it may lead to a few hours of unnecessary downtime.

A feature that he thought could be added is the planned maintenance. Now, the maintenance that has to be executed daily, weekly, yearly, etc. is documented in an Excel spreadsheet, which the operators have to fill in every day. This could be merged into this dashboard, having everything in one application.
Furthermore, the tool usage and maintenance history could be an additional feature, according to him. With this data, the amount of tools used can be seen and compared to last year for example, to see if you made improvements.
As the dashboard is about increasing the uptime, data should be presented about the change in uptime and maintenance time. Another recommendation is that when putting a tool

back in the inventory, the dashboard should keep track of its RUL and location, so it can be used again with the corresponding RUL.

To prevent any major changes at the end of the project, a weekly evaluation of the design in Figma is done with my supervisors from Voortman. This way, constant feedback is given and implemented into the design, leading to an already evaluated end product, ready for the evaluation phase.

6.2 Final design

In this section, the final design will be described. The design consists of two parts, where the main part is the prescriptive maintenance dashboard for the production manager, and the other part is the phone dashboard for the operator. The different frames will be explained, what data they present and how you can interact with it. At last, the limitations due to time, Figma or other factors will be mentioned. A link to the prototype can be found here [37].

6.2.1 Production manager's dashboard

The dashboard for the production manager is the main part of this prototype, as he is the target audience. The dashboard made in Figma is focused on presenting data and actionable feedback to the production manager, to prevent unplanned maintenance which will lead to an increase in the uptime. The frames, screens or 'pages' in this dashboard will be explained one by one, and with the link to the

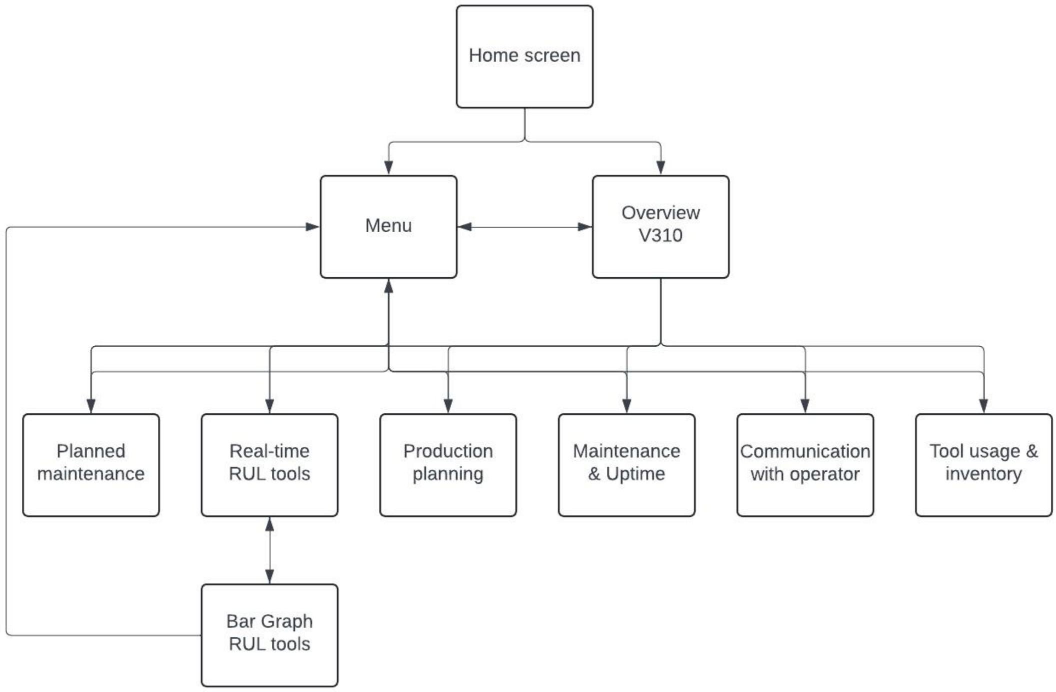


Figure 6.4 Schematic diagram of the menu structure

prototype in the introduction of this chapter, you can click through the design and interact with the different frames, which can be seen in figure 6.4.

Menu

At each frame, the menu can be found. When clicking on this menu, it expands and quick navigation through the whole dashboard is made possible. The EVI logo is a return to the home screen. Furthermore, an operator can be found in the menu. This button will navigate you to the communication with the operator frame, allowing fast communication (figure 6.5).

Figure 6.5. Hamburger menu

Home screen

When starting the prototype, the home screen pops up. On this screen, the different machines can be selected to see their corresponding data. However, as the design is only made for one machine, the V310, the other machines are set to 'disconnected'. When maintenance is required soon, a warning sign will pop up above the machine, so the production manager can already see on the main screen which machine requires maintenance soon. By clicking on a certain machine, the user will be navigated to dashboard of that machine.

Dashboard V310

This is the main frame of the dashboard for the V310. Here, the user can navigate to six different frames, which are explained below. On frames where maintenance is needed, a warning sign can be seen at the top right, so the production manager does not have to search for it himself. When clicking on the machine at the top right or at the 'back' arrow at the top left, the user will navigate back to the home screen (figure 6.6). The menu items are numbered 1-6 and will be discussed consecutively.

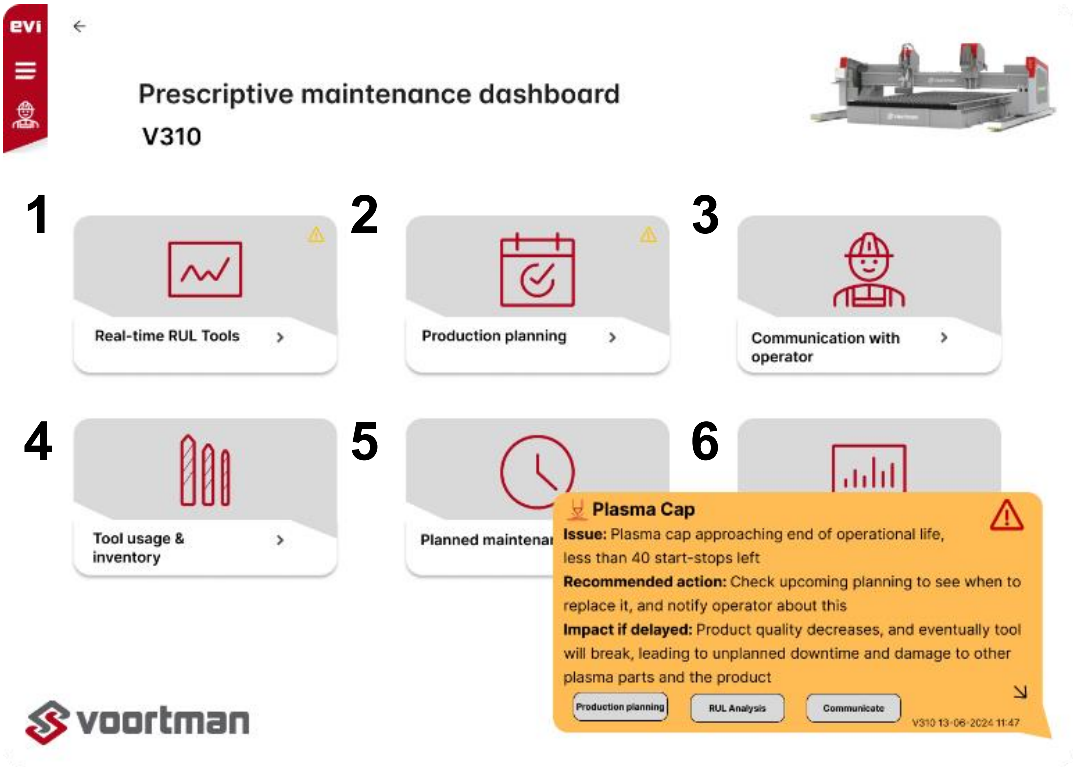


Figure 6.6. Main dashboard of V310

Real-time RUL tools (1)

In this frame, data is presented on the real-time RUL of the tools that are currently in the machine. The percentages of how much RUL is left on the tools can be seen, along with a bar graph with indicating colours based on tool health. At the left side is the tool type, and at the right side the maximum tool life. When a tool is almost at the end of its operational life, a button pops up which says ‘Tool changed’. When a tool is replaced, the production manager can click on this button and the value will reset. The machine settings can also be adjusted on this screen, by clicking on the dropdown menu at the top. You can choose between ‘Eco-mode’, ‘default’, and ‘performance’. Based on the choice, the graph will show the corresponding RULs of the tools. Eco-mode means that the machine runs slower and more economically, leading to an increase in the maximum tool life. Performance mode is the opposite, and means that the machine will run faster, leading to a decrease in the maximum tool life, as the tools will be worn out faster.

When clicking on the bar graphs, it will navigate the user to the RUL analysis frame, where two bar graphs can be seen. In these graphs, the current tools can be seen again, with their corresponding tool health and RUL. Furthermore, the critical zones when a tool needs to be repaired or when it theoretically fails are located at the end of the graph. When clicking on the ‘back’ arrow at the top left, the user will return to the real-time RUL dashboard (figure 6.7).

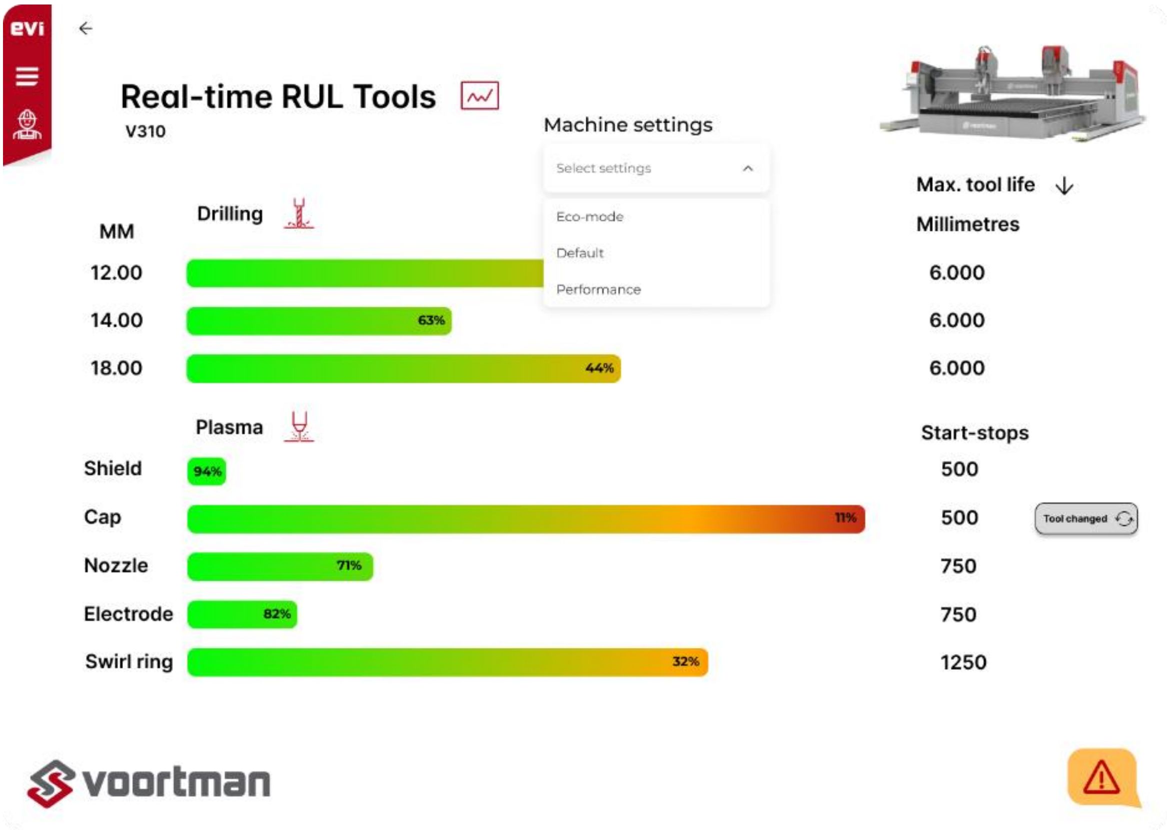


Figure 6.7. Real-time RUL tools overview

Production planning (2)

Moving on to the production planning screen, where the upcoming projects for that day can be seen. This is a dropdown menu, meaning that the user can only expand the projects you would like to get more details on. When clicking on a project, it expands and shows what tools are needed, if they are available in the machine, how much millimetres or start-stops they have to do in that project, and what the RUL will be after the project, theoretically. This will help to see whether the machine will finish a project with the current tools, or that the operator has to replace them. A warning sign pops up when RULs almost end, or when tools need to be added manually to the machine before the project. By hovering over the warning sign, details of the warning can be seen (figure 6.8).

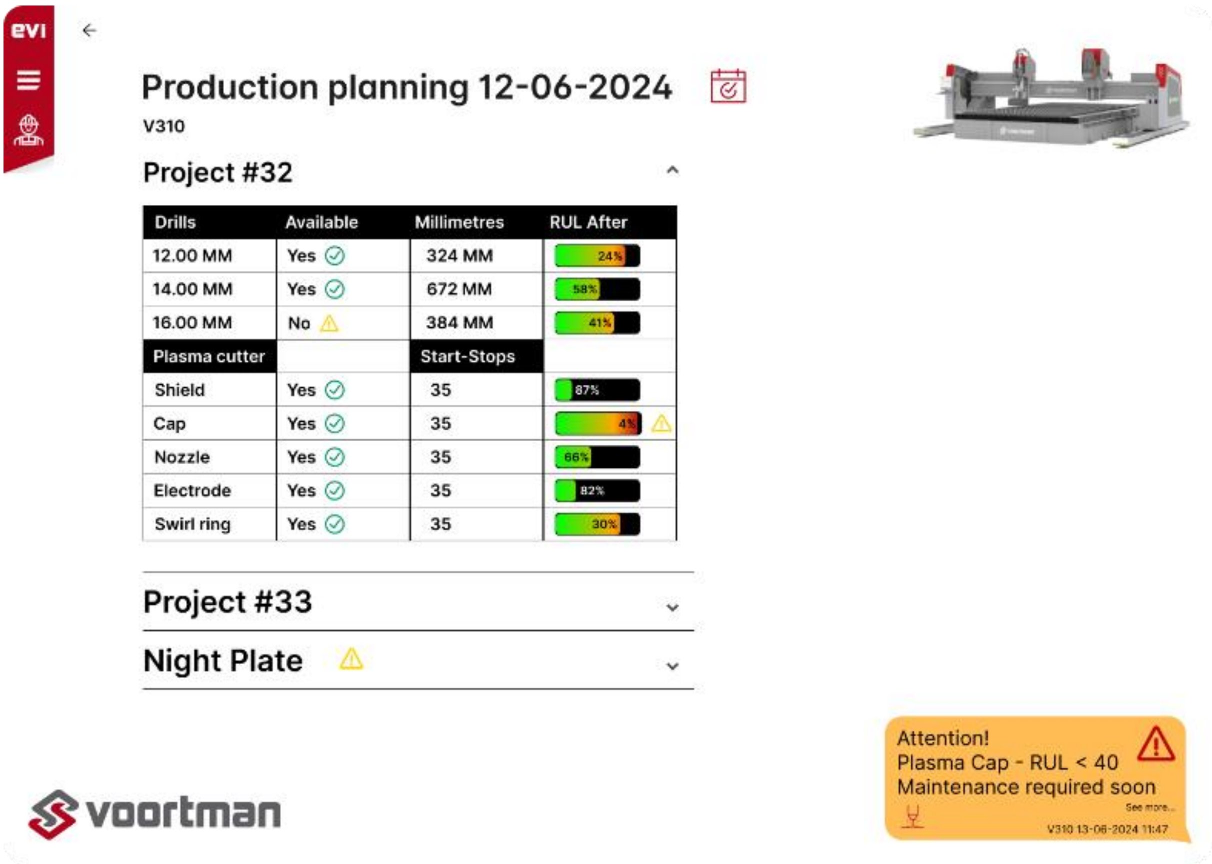


Figure 6.8. Upcoming production planning

Communication with operator (3)

Continuing with the communication screen, which is directly accessible through the menu bar. Here, the production manager can type messages to the operator, for example instructions to change a specific tool before the start of a new project (figure 6.8).

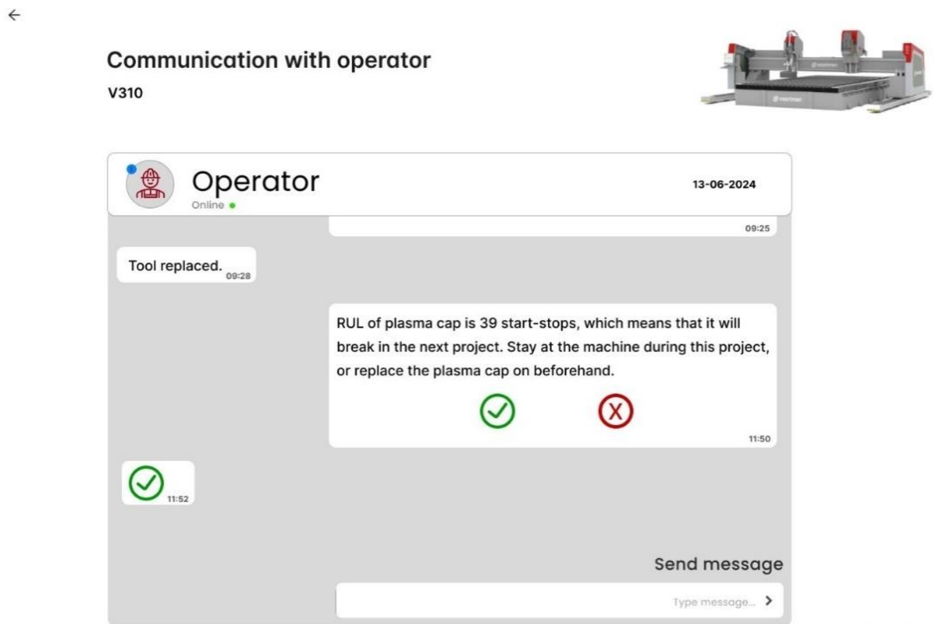


Figure 6.9. Communication with operator

Tool usage & inventory (4)

To get more insights in how much tools you used in the last weeks, months or years, a bar graph has been made. Here you can see that the amount of tools used decreases when you compare 2022 with 2024. This, because the tools will be used more efficiently, leading to less maintenance costs.

In the tool inventory dropdown, data is presented of tools that have been used by the machine, but can be used again. The corresponding RUL is also shown, so the production manager knows which tool can last how long. The location of the tool can also be seen, to make it easier for the production manager to communicate it with the operator (figure 6.10).

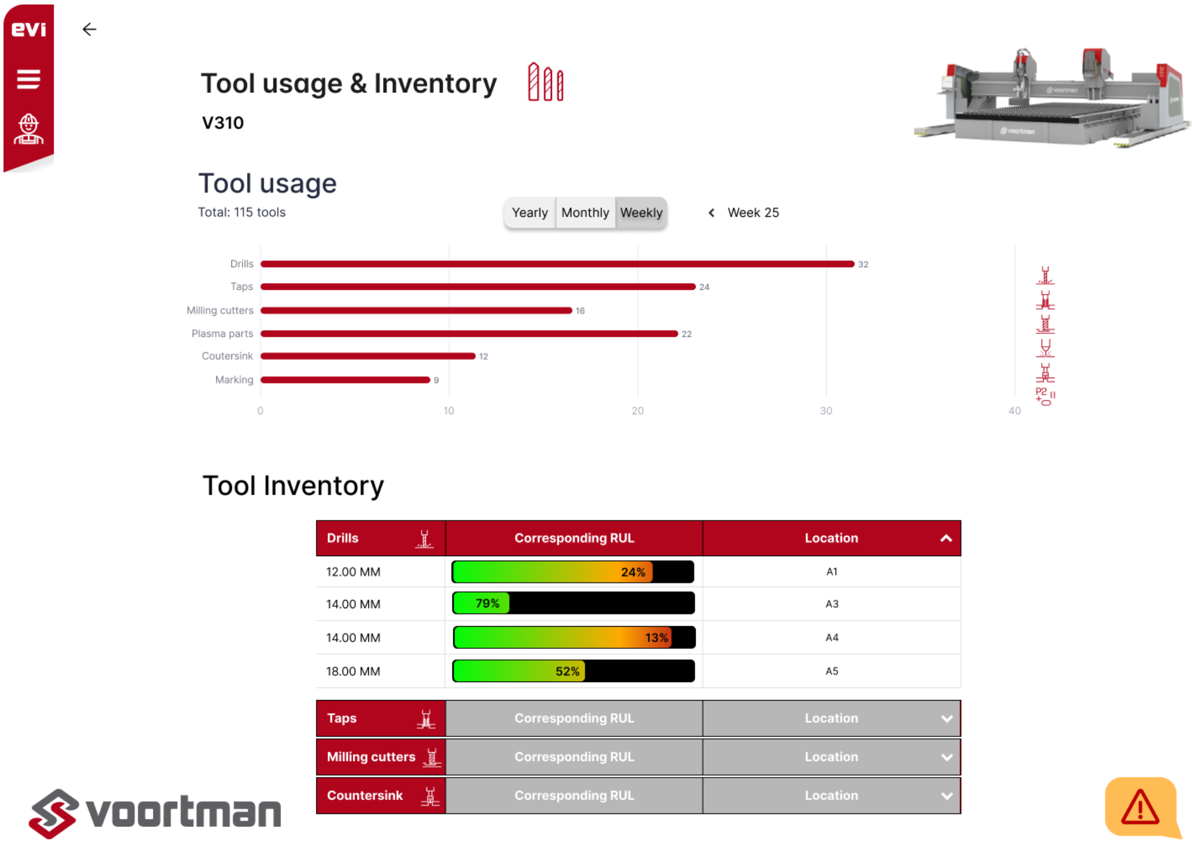
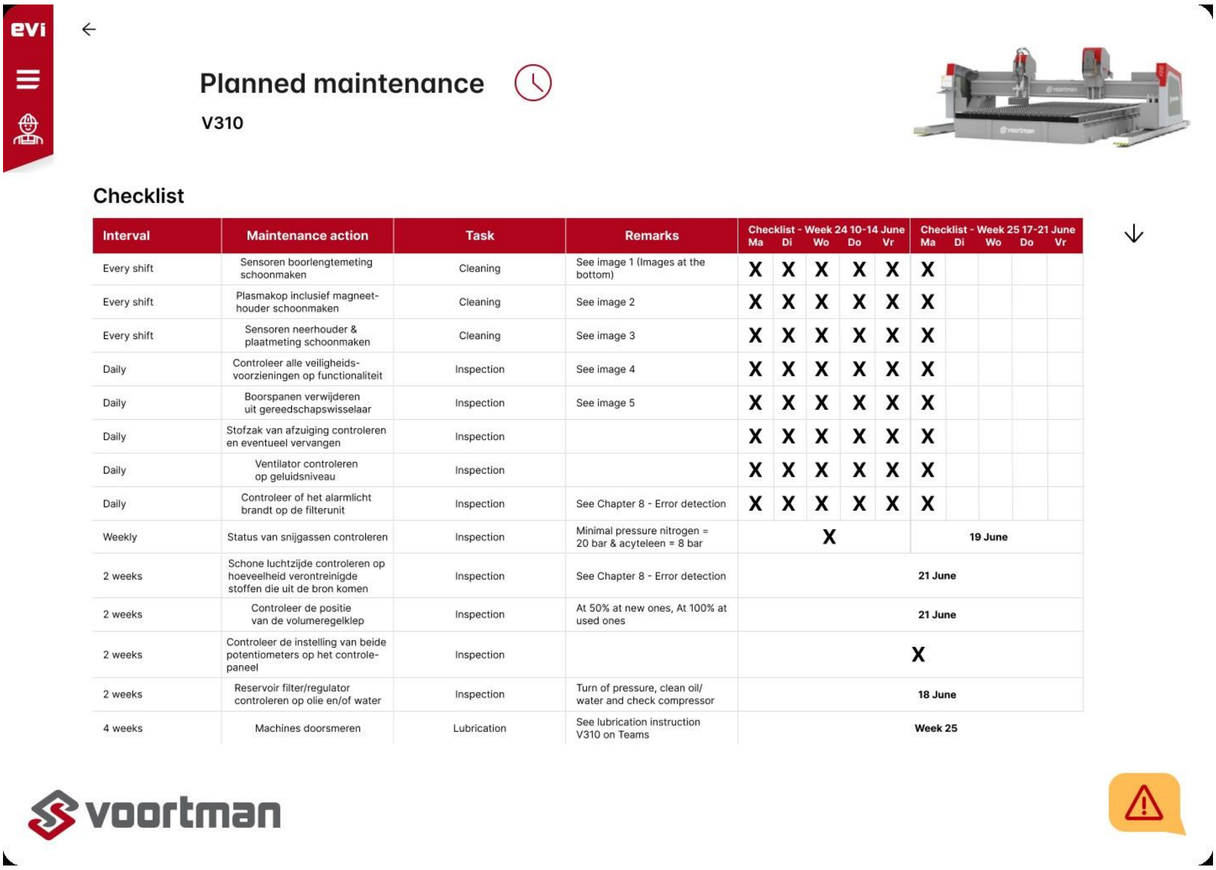


Figure 6.10. Overview of tool usage and inventory

Planned maintenance (5)

In the planned maintenance frame, an overview of all the planned maintenance tasks can be found. These are tasks that need to be done daily, weekly, monthly, etc. A checklist is also included, to keep track of whether the maintenance is executed or not. Images with explanation can be seen when you scroll to the bottom (figure 6.11).



Interval	Maintenance action	Task	Remarks	Checklist - Week 24 10-14 June Ma	Di	Wo	Do	Vr	Checklist - Week 25 17-21 June Ma	Di	Wo	Do	Vr
Every shift	Sensoren boorlengtemeting schoonmaken	Cleaning	See image 1 (Images at the bottom)	X	X	X	X	X	X				
Every shift	Plasmakop inclusief magneet-houder schoonmaken	Cleaning	See image 2	X	X	X	X	X	X				
Every shift	Sensoren neerhouder & plaatmeting schoonmaken	Cleaning	See image 3	X	X	X	X	X	X				
Daily	Controleer alle veiligheids-voorzieningen op functionaliteit	Inspection	See image 4	X	X	X	X	X	X				
Daily	Boorspanen verwijderen uit gereedschapswisselaar	Inspection	See image 5	X	X	X	X	X	X				
Daily	Stofzak van afzuiging controleren en eventueel vervangen	Inspection		X	X	X	X	X	X				
Daily	Ventilator controleren op geluidsniveau	Inspection		X	X	X	X	X	X				
Daily	Controleer of het alarmlicht brandt op de filterunit	Inspection	See Chapter 8 - Error detection	X	X	X	X	X	X				
Weekly	Status van snijgassen controleren	Inspection	Minimal pressure nitrogen = 20 bar & acyteleen = 8 bar			X					19 June		
2 weeks	Schone luchtzijde controleren op hoeveelheid verontreinigde stoffen die uit de bron komen	Inspection	See Chapter 8 - Error detection						21 June				
2 weeks	Controleer de positie van de volumeregelklep	Inspection	At 50% at new ones, At 100% at used ones						21 June				
2 weeks	Controleer de instelling van beide potentiometers op het controle-paneel	Inspection							X				
2 weeks	Reservoir filter/regulator controleren op olie en/of water	Inspection	Turn of pressure, clean oil/ water and check compressor						18 June				
4 weeks	Machines doorsmeren	Lubrication	See lubrication instruction V310 on Teams						Week 25				

Figure 6.11. Planned maintenance checklist

Maintenance & Uptime (6)

If the production manager wants to know what effect the dashboard has on the maintenance and uptime of the machine, they should go to this frame. There is a bar graph in combination with a line graph, which shows the percentage of predicted and unplanned maintenance, and the average maintenance time in hours. As can be seen, over the past year, the unplanned maintenance decreased a lot, and became predicted maintenance instead. Also, the average maintenance time decreased, because unplanned breakdowns are prevented. Furthermore, the average machine status per quartile can be seen in the pie chart. When comparing Q2 2024 to Q3 2023, it can be seen that the uptime (running automatically) is increased and the maintenance is decreased, as a consequence of the implementation of this dashboard (figure 6.9).

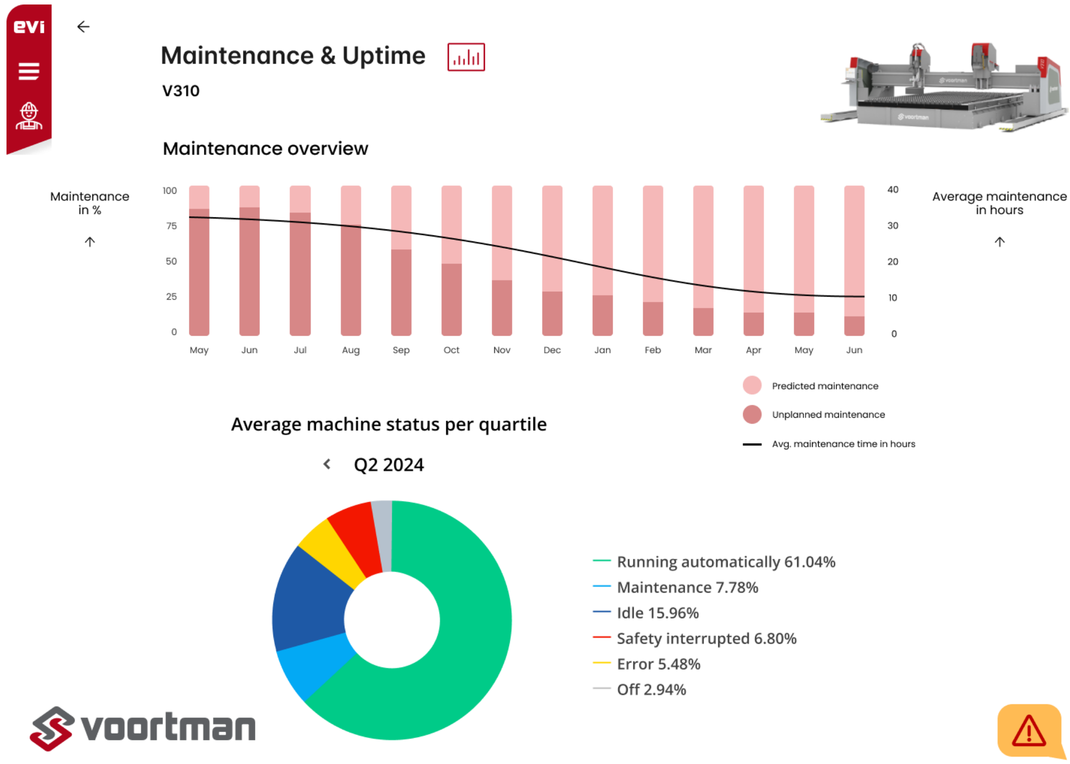


Figure 6.12. Overview of maintenance and machine status

Notification

After a delay, a notification will pop up from the machine at the bottom right on the dashboard for the production manager, and in the middle for the operator's phone, saying that a tool is almost at the end of its operational life. Furthermore, a warning sign can be seen at the start, where the user has to choose a machine. The warning signs can also be seen at the specific tool that needs maintenance. This means that the production manager does not need to look the whole day to the dashboard, the notification will let him know quickly when maintenance is needed. When clicking on the notification, it expands and provides more details about the maintenance. Furthermore, buttons will show up and can be clicked to navigate to the production planning, to the RUL analysis screen or to communicate it with the operator. By clicking on the diagonal arrow, the notification will collapse so it does not interfere with the screen, but it is still visible. By clicking on it again, the notification will expand again. This notification can be seen in figure 6.5 & 6.7.

6.2.2 Operator's phone

To receive notifications from the operator, and to keep track of the planned maintenance tasks, a phone dashboard has been made. To not increase the cognitive load of the operator, the dashboard has been kept simple and intuitive, where the operator only has to press a few buttons.

Figure 6.13. Operator's phone menu

Menu

The menu is small, as the dashboard only has 3 screens. It is accessible at the bottom left of the screen. Here, the user can navigate to the maintenance details and the planned maintenance checklist, or go back to the machine overview. By pressing on the EVI logo, you will navigate back to the machine overview screen (figure 6.13).

Machine overview

This is the home screen of the dashboard, and gives an overview of the machines and their current status. This way, operators might notice when a machine stops running, and can take action. Furthermore, a blue dot pops up if the production manager has send a new message. By clicking on the machine the operator is working with, he will navigate to the maintenance details screen (figure 6.14).

Figure 6.14. Machine overview

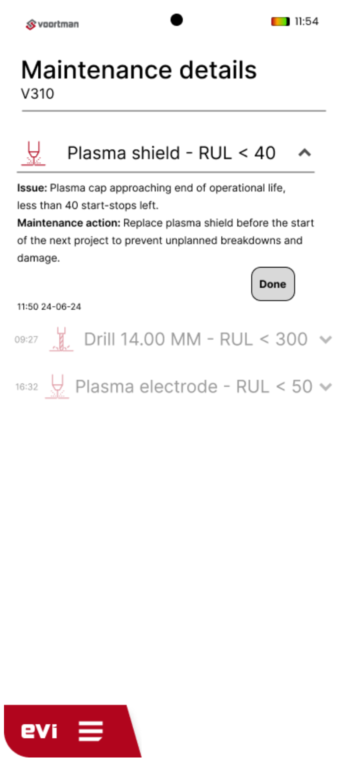


Figure 6.15. Maintenance details

Maintenance details

On this screen, maintenance history and new maintenance actions are shown. Actions that are completed are turned grey, and new maintenance actions are at the top, in black. This is again a dropdown menu, with the details of the action provided in the expanded version. When the menu is expanded, the operator can read the instructions, and press on the 'done' button when the action is executed. This will set the action to done, and the blue dot will disappear.

Planned maintenance

In this frame, a simplified version of the planned maintenance actions can be found. The tasks are explained with the corresponding images, and the operator can mark the actions with an ‘X’ if it is finished, to keep track whether a maintenance actions is done.

Notification

When a production manager sends a notification, it will pop up at the operator’s phone with a sound. The notification says that maintenance is required within a period of time, and the operator can choose to remind him later or to look at the details of the maintenance action. When he chooses the last one, he will navigate to the maintenance details frame, which is explained above. Otherwise, the notification will pop up a few minutes later (figure 6.17).

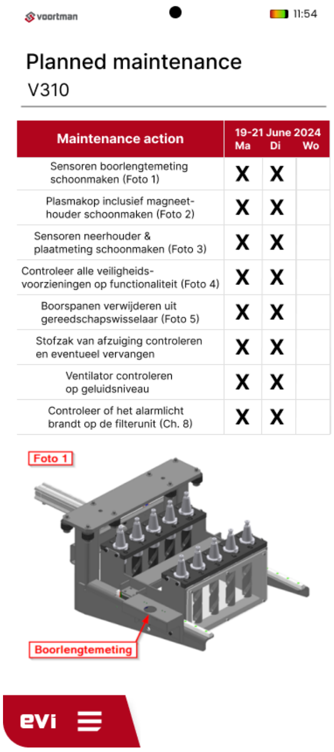


Figure 6.16. Planned maintenance checklist

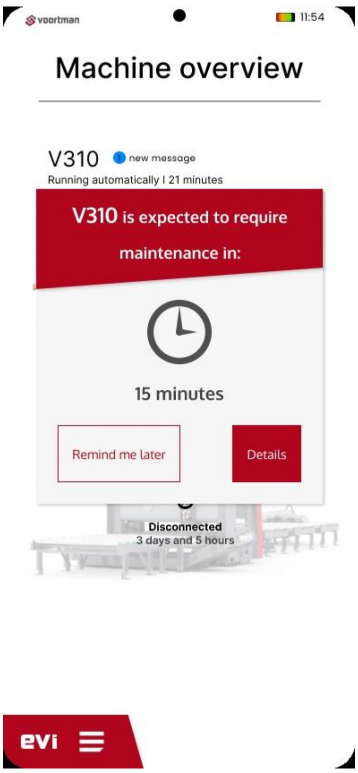


Figure 6.17. Notification on the phone

Chapter 7 – Evaluation

In this chapter, the evaluation of the prescriptive maintenance dashboard takes place. This evaluation contains two parts, the functional evaluation conducted by the researcher of this project, and the user testing with an external production manager, and other people from Voortman to have different perspectives on the prototype and to evaluate the non-functional requirements.

7.1 Functional evaluation

During the functional evaluation, the designer of the prototype will check whether the prescriptive maintenance dashboard meets all the functional requirements. Furthermore, all functionalities, buttons and interactions will be tested, to ensure everything works as intended.

The evaluation results were positive, and almost every functional requirement from the 'must' and 'should' category were easily fulfilled. Also a few requirements from the 'could' category were met. A detailed analysis can be seen below, where each requirements is discussed individually if they were met and how:

Must

- Must show data on the RUL (Remaining Useful Life) of tools and machine parts
  The dashboard provides information about the RUL of tools with colours, percentages and maximum tool life.
- Must provide recommendations on what to do based on that data
  The dashboard presents a recommended action in the notification and at warning signs when maintenance is required, which is the actionable feedback part.
- Must generate warnings or alerts to the production manager when tools are nearing the end of the RUL
  The dashboard presents a notification with information about the specific tool that needs maintenance. However, it does not use real-time data so notifications are shown based on a delay.
- Must reset the RUL when a component is replaced
  The dashboard has an option to reset the RUL value of a tool when it has been replaced. However, this needs to be done manually by the production manager, because Figma does not allow interactions between two screens or devices.
- Must deliver notifications to the operator without delay
  The notification pops up after a delay of 5 seconds, and is always in time.

- Must notify the operator by vibration and sound alerts
  The notification on the operator's phone comes only with sound, as Figma does not support vibrations.
- Must allow operators to confirm task completion back to production manager
  Operators can mark off a maintenance action as 'done' in the application, and it will be turned grey. However, as said, interactions between the two dashboards is not possible, which means that there is no feature to receive a task completion.
- Must show improvements on maintenance time based on initial state
  The dashboard shows theoretical data on the possible effect of the implementation of the dashboard. There is a graph with the maintenance division in % versus the average maintenance time in hours, and a graph with the average machine statuses in the past quartiles, including maintenance and uptime.
- Must be compatible on various devices, such as a laptop and a phone
  Both dashboards work at both devices.
- Must include continuous operation
  The idea behind the dashboard and the actual implementation of it would include continuous operation because of the use of real-time data. However, the dashboard only uses historical or created data, meaning that the concept is not continuous right now.

Should

- Should allow to edit messages before sending them
  Production managers can type their own message.
- Should take into account the production planning, and if it can be theoretically achieved with the current tools
  The dashboard provides information on the upcoming planning, what tools are needed and if the tools will last through the project.
- Should include details in the notification, such as the issue, the recommended action and the impact when action is not taken
  The notification to the production manager and operator contains the issue, the recommended action and the impact if the action is not taken.
- Should include the option to change the machine settings and see the corresponding RUL
  The production manager can change the machine settings in the real-time RUL tools dashboard, where the RUL values and the maximum tool life changes to the corresponding settings.

- Should show a tool inventory with the corresponding RUL and where they are located
  The dashboard shows an inventory with the tools that have been used already, but still have enough RUL to perform operations. The location is also mentioned, to quickly tell the operator which tool to pick.
- Should work on various operating systems, such as Windows, macOS and Linux
  The dashboard works on all devices that can run Figma.
- Should be designed in an interface design application, to focus on the presentation of the data rather than the technical aspects of collecting the data
  The dashboard is designed in Figma, which is an interface design application and focuses more on the looks and interactions of an application.
- Should give an overview of the planned maintenance, and if it's done or not
  Both dashboards provide the planned maintenance checklist, with information on what to do and the operator can check the boxes if the actions are executed.
- Should possibly be integrated in EVI, when the data is available
  The dashboard uses components from EVI and the design and interface are similar, meaning that when data is available, this concept idea can be integrated into EVI.

Could

- Could provide reports that summarize the maintenance activities
  -
- Could present advice on the machine settings by letting the system know how you want to produce
  -
- Could show historical data on tool usage
  The dashboard shows the tools used in the past week, month and year.
- Could give an overview of the average tool life to give more accurate information about the RUL
  -
- Could support multiple languages as some people are more comfortable with another language
  -

When it comes to the functionality of the dashboard, a few changes in the interactions and the buttons are corrected, and the phone dashboard size is changed to meet the iPhones 12-14. Everything now works as intended.

7.2 User testing

Moving on to the user testing, where the dashboard will be evaluated with different people. Before the evaluation, the project and the goal of the prototype will be explained, whereafter the participant will navigate his way through the dashboard, while thinking out loud. Explanations of the frames will be provided by the researcher if necessary, and the participant will be observed while the researcher takes notes during the process. After the whole dashboard is explored, a few questions will be asked about the dashboard, together with the technology acceptance questionnaire [38]. This questionnaire includes a likert-scale about the perceived usefulness and the ease of use of the prescriptive maintenance dashboard, where the participant will rank the statements from 1-5, where 1 is 'absolutely not' and 5 is 'yes, very'. The statements are in Dutch, as all the participants were Dutch. The questions can be found in appendix E. However, as it was not a structured interview but more of a conversation, questions or topics that rose up were also discussed.
In total, three people have evaluated the prescriptive maintenance dashboard according to the above-mentioned approach. Two people from Voortman, a product manager plate machine and a test technician, and one person, a production manager, from an external company. The duration of the tests was about 20-30 minutes for all evaluations. Furthermore, to prevent any major changes in the end, the dashboard is evaluated every week with the supervisors.

7.2.1 Product manager plate machines

The first evaluation was with the product manager of the plate machines. Product managers are focusing on developing and exploring new ideas that will deliver value or interest to their customers and improvement to the product, the plate machines.

While and after navigating through the dashboard, he mentioned a few things he found positive or questionable:

- + By instructing the operators to change or add certain tools, you are well prepared for the upcoming production planning. This is especially at night important, because if then a tool breaks, there is no operator present to fix that, and a few hours of uptime is lost.
- + Changing tools in time will increase the product quality, especially with plasma tools, as the cuts won't be as neat and accurate if the RUL is low.
- + For the production managers it's really interesting to see the uptime of the machine in comparison with the maintenance, to identify trends and to see how effective the dashboard is.

+ The phone dashboard for the operator is really handy, it’s clear and simple, just as it should be.
+ Both the dashboards were really intuitive, the order makes sense and the interactions were smoothly.
- He doubted if the production manager is actively going to tell the operator each time to change a certain tool, as the operators also get a notification in VACAM, the software on the machine. However, when the operator is not near the machine, he might not notice this notification which will lead to an unnecessary amount of downtime.
- He would like to see the average distance per tool, in combination with the tools used, as using less tools doesn’t necessarily mean that the production is more efficient, it could also be that the productivity decreased. This will help to make a safer and accurate choice on what the maximum RUL is.

Perceived Usefulness (1 – Absolutely not, 5 – Yes, very)

1. Using this product at work would allow me to complete tasks faster. **Score: 2**
2. Using this product would improve my performance at work. **Score: 3**
3. Using this product would increase productivity. **Score: 5**
4. Using this product would enhance my effectiveness at work. **Score: 4**
5. Using this product would make it easier to do my job. **Score: 4**
6. I would find this product useful at work. **Score: 4**

Average: 3.67/5

Ease of Use

7. Learning to operate the product would be easy for me. **Score: 5**
8. I would find it easy to get the product to do what I want it to do. **Score: 5**
9. My interaction with this product would be clear and understandable. **Score: 4**
10. I would find this product flexible to work with. **Score: 4**

Average: 4.5/5

In the questionnaire, all questions received a 4 or 5, except for questions 1 and 2. That might be because the prescriptive maintenance dashboard does not allow users to necessarily complete task faster, but rather more efficiently. Also, the goal of the prescriptive maintenance dashboard is to increase the performance of the machine, not of the production manager or the operator. Furthermore, the participant was not sure if the dashboard would be used for every maintenance action that needs to be executed, as operators also already perform some maintenance by themselves.

7.2.2 External production manager

The second evaluation was with the production manager from an external client of Voortman. This company uses Voortman machines together with EVI, which makes him the ideal person in the target audience. He was enthusiastic about the design, and was mostly positive about it:

- \+ The dashboard keeps track of the maintenance actions, which ensures that everything will be done.
- \+ The product quality will increase, as unplanned breakdowns will be prevented and worn out tools will be replaced on time.
- \+ When integrating this dashboard in EVI, it will become a helpful, assisting tool rather than a monitoring application.
- \+ It not only ensures increase in uptime due to more efficient maintenance, it will also help to produce more efficiently, and will decrease the production costs.
- \+ Looking forward to the upcoming production planning, what tools you need and if they will last through the project.
- \+ When using the dashboard for a while, historical data will be build up which allows to identify trends or particularities, where even more improvements can be made based on that data.
- \+ More insights into the machine is always handy, you will get a better view of your performance.
- \+ The dashboard and the graphs were clear at a glance, you know directly what you are looking at.
- \+ Interactions between the frames are smooth, no delay issues or buttons that don’t work.
- \+ More information about the uptime and factors that have an influence on that (maintenance) is always interesting to see, especially in combination.
- \+ When an operator has time left, he might do some optional maintenance actions to use his time more efficient.
- \+ The phone dashboard is really interesting, as operators can quickly view what maintenance is done and what not, and can mark the action as finished if they executed it.
- ± In VACAM, the operator gets already a notification if the RUL is surpassed, and most of the time he is standing next to the machine, so not every tool that reaches the end of its operational life should first pass by the production manager. However, by also

sending notifications to their phones, they will recognize it even faster when a tool needs to be replaced.

- He wasn't sure if he was going to actively use the dashboard, but that's also not the goal. The goal is to have the dashboard running on the background, and when there is something wrong, a notification will pop up. The same for the historical data in the dashboard, it doesn't require 24/7 attention, but is more to give a quick overview of the maintenance when you want to know more about it.

Perceived Usefulness (1 – Absolutely not, 5 – Yes, very)

1. Using this product at work would allow me to complete tasks faster. **Score: 3**
2. Using this product would improve my performance at work. **Score: 3**
3. Using this product would increase productivity. **Score: 4**
4. Using this product would enhance my effectiveness at work. **Score: 4**
5. Using this product would make it easier to do my job. **Score: 5**
6. I would find this product useful at work. **Score: 5**

Average: 4/5

Ease of Use

7. Learning to operate the product would be easy for me. **Score: 5**
8. I would find it easy to get the product to do what I want it to do. **Score: 4**
9. My interaction with this product would be clear and understandable. **Score: 5**
10. I would find this product flexible to work with. **Score: 4**

Average: 4.5/5

To conclude the questionnaire results, the same pattern can be seen here as in the evaluation with the product manager. All statements are rated with a 4 or 5, but the first two questions are rated lower. The external production manager had the same thoughts as the product manager, that he was doubting if the dashboard will be used for every maintenance action on the machine, as operators can perform some of them themselves. He suggested a feature in the dashboard where the production manager can see whether the operator has seen the notification on the dashboard at the machine, so he only has to send a message when the operator hasn't seen the notification.

7.2.3 Test Technician

To also get a perspective of someone who is more experienced at the shopfloor and actually works with the machine, a user test with a test technician is conducted. He is similar to an

operator, as he controls the machine and runs production. The difference is that the test technician focuses more on testing and repairing the machine when maintenance is needed, so he also has more knowledge about maintenance.
He brought some new insights and another perspective on the design, which helps to identify the impact of the dashboard on different people's work:

+ The operator can easily check off what maintenance actions are done to ensure well prepared production which will lead to an increase in the uptime.
+ The notification system in combination with the operator's phone ensures fast action-taking when a message comes in, especially when the operator is not close to the machine.
+ Making good use of the tool inventory will lead to a significant decrease in tool costs, as you will get the most out of your tools before they are thrown away.
+ The production costs decreases as tools are used more efficiently, and unplanned breakdowns are prevented, which would otherwise lead to more downtime.
+ By showing the uptime in the dashboard, the production manager can easily check if the uptime increases when the maintenance is mostly planned.
+ Operator's phone does not distract him to much with the notifications, but only if it not becomes annoying or disturbing.
- A bad relationship between production manager and operator can lead to inefficient use of the dashboard.
- Communication with operator can maybe done differently, for example with a collaborative file where the production planning can be seen, and where maintenance actions can be added to.
- The dashboard does not capture unexpected tool breaks, leading to inaccurate data.

Perceived Usefulness (1 – Absolutely not, 5 – Yes, very)

1. Using this product at work would allow me to complete tasks faster. **Score: 4**
2. Using this product would improve my performance at work. **Score: 4**
3. Using this product would increase productivity. **Score: 4**
4. Using this product would enhance my effectiveness at work. **Score: 4**
5. Using this product would make it easier to do my job. **Score: 3**
6. I would find this product useful at work. **Score: 5**

Average: 4/5

Ease of Use

7. Learning to operate the product would be easy for me. **Score: 5**

8. I would find it easy to get the product to do what I want it to do. **Score: 3**
9. My interaction with this product would be clear and understandable. **Score: 5**
10. I would find this product flexible to work with. **Score: 4**

Average: 4.25/5

To conclude the questionnaire results, it can be seen that the first two questions are now rated with a 4, but the 5th question is answered with a 3. This might be because the operators have to do slightly more work and have to communicate more about what they have done and what is coming up, which might increase their cognitive load and thus does not make their job easier, but more complicated even. Furthermore, there was some confusion when trying the dashboard, as it was not fully clear whether some functionalities work or not. That is why the 8th statement was rated with a 3.

7.2.4 Discussion on evaluating the non-functional requirements

After the evaluation, the non-functional requirements will be discussed whether they are met or not, and how.

Must

- Must equip the production manager to increase the uptime of the machine
  By providing actionable feedback, the participants thought that the production manager would be encouraged to actively interact with the operator to manage the maintenance as efficiently as possible. However, some actionable feedback was too obvious, which makes it sometimes unnecessary.
- Must not distract the operator so it creates dangerous situations
  The phone makes a small message sound when a notification is coming in, which won't distract the operator as he has already much noise around him. Furthermore, the notifications are given on time, meaning that he does not have to look at it immediately.
- Must not increase the cognitive load of the operator
  As can be seen in the questionnaire score, the test technician thought that the dashboard could increase the cognitive load a bit, but this would be minimal. The external production manager said that when the dashboard is well integrated in the company and everyone knows how to work with it, this would not be a problem for the operators.
- Must integrate seamlessly into the production manager's and operator's work environment
  As the dashboard is more or less passive, meaning that it should not be looked at all

day, the dashboard can be in the background. When a notification pops up, the production manager can take action. However, the production manager and the operator still decide themselves what to do, meaning that they are not forced by the dashboard to execute certain actions they don't want to do. This means that it is not disturbing, and that it integrates in their environment.

- Must comply with data and security rules
  No real-time data or personal information is used, so this does not apply.
- Must be intuitive for the user
  After the user-testing, all participants agreed on how intuitive and user-friendly the dashboard is, and that directly can be seen what's on the screen.

7.3 Conclusion

By looking at the results from the evaluations that have taken place, a conclusion can be drawn that the prescriptive maintenance dashboard meets the functional requirements, except for that the phone of the operator can't vibrate, as that is not possible in Figma. This is a minor issue, as it does not affect the interactions and presentation of the data in the dashboard. Looking at the non-functional requirements, they could only be tested with user evaluations, as the dashboard can't be tested on the machine in their daily work routine. However, after conducting several user tests, it can be concluded that the dashboard fulfils most of the requirements based on the answers provided by the participants. The only requirement that not really applies is about data and security rules, as the dashboard does not use real-time data. However, as said, it was not a possibility to test the dashboard in the actual Voortman environment, which means that the results are not 100% valid yet. This will further be discussed in chapter 8.

Chapter 8 – Discussion & Future Work

Moving on to the last part of the Creative Technology design cycle, the findings of the evaluation will be discussed along with the expectations before the evaluation took place. Furthermore, the projected will be reflected upon, but also a personal reflection will be included in this chapter. Furthermore, the possible implementation and future work of the design is discussed, to see how the project might look like if there were no limitations and if the design was actually implemented in EVI.

8.1 Discussion

Expected results

Before the evaluation, there were a few expectations of what the results would be. As providing real-time information about the RUL of tools was the main part of the dashboard, the expectation was that the participants would be the most interested in this. However, this was not the case, as operators already do get information when a tool needs to be replaced. The part they were more interested in was that the production manager and the operator can prepare for the upcoming planning, by seeing what tools are needed and whether they will make it through the project. Furthermore, the external production manager was interested in the planned maintenance checklist, as this keeps track of whether the maintenance actions are executed or not. This has also to do with looking forward and preparing for a smooth and efficient production.
Talking about the ease of use of the design, it was expected that the dashboard would be intuitive and easy to navigate through, which was validated by the technology acceptance questionnaire and the interview after the user-testing. All participants thought that the dashboard was user-friendly, and that immediately can be seen what they were looking at.

Validation

When it comes to validating the prototype, there was also a limitation. This was mostly because the dashboard does not use real-time data, which means that the dashboard could not be implemented on the machine to see if it would increase the uptime by managing maintenance more efficiently. This would be a future step.

Problem statement

In the beginning of this project, the problem statement was not yet clear, because there were a lot of factors that had to be researched, and many things were still unknown, also for the people at Voortman. That is why it took a while before the project had a clear problem statement and research question to work with. But by conducting many interviews and doing proper literature research, the problem became clear and a solution was identified and realised.

Limitations

To discuss the evaluation, a few limitations are listed which influenced the prescriptive maintenance dashboard and the outcomes of the user tests, along with how the limitations are dealt with.

At first, the dashboard does not use real-time data, for a few reasons. Applying real-time data requires technical knowledge which costs time to acquire. The prototype is also focusing on the presentation of the data, rather than if the data itself is correct or real-time. Lastly, Figma does not allow real-time data input, so then the dashboard should be made in a different application. This issue is solved by using historical data, or by creating data for the prototype.

Another limitation is that the communication between the production manager's dashboard and the operator's phone does not work, as Figma does not allow two screens at the same time interacting with each other. This is solved by adding notifications based on a delay of a few seconds. This means that when the dashboard starts up, a notification will pop up after a few seconds, making it look like a production manager has send a message.

Furthermore, the dashboard is only using theoretical values and scenarios. When a tool with an RUL of 83% breaks suddenly, the dashboard does not keep track of it. However, the value of the RUL can be reset by the production manager to ensure that the values are correct.

When it comes to the front-end of the dashboard, it was not always clear where the user can interact with or not. This caused some confusion during the evaluation, where the participants where clicking on components which could not be interacted with. After a quick explanation on the possible interactions of the dashboard, this became more clear.

The last limitation is that the dashboard can't be tested in real-life on the machine, to see if it works. The dashboard is not connected to EVI or the machine, and the data is not yet available from the machine. That problem will be solved by evaluating the dashboard with experts, production managers and other people to get an indication of how effective the dashboard will be.

8.2 Future Work

Here, the possible further steps of the project and the prescriptive maintenance dashboard will be discussed, whether it is the use of the dashboard or potential features that might be added to it.

First, a future step of the project could be the actual implementation of the dashboard at the customer's company. This would mean that the dashboard should use real-time data, and provide actionable feedback based on that to the production manager. Then, it can also be validated if the dashboard reaches its goal, namely to optimize machine output.

Future features of the dashboard might be that it could present data on the energy usage of the machine, providing more information to the production manager on how sustainable their production is, how much the costs are and where improvements can be made. This can prepare steel manufacturers for possible new rules about CO2-emissions, as the steel industry has a high contribution to polluting the environment [39].

Another feature might be that the production manager receives a summary of the productivity and the maintenance statistics of last week. This gives a quick and clear overview of the maintenance management versus the uptime, and can easily be compared to other weeks which might lead to identifying trends or issues to optimize the productivity even more.

The last future step is that the dashboard could show information of all machines, instead of only one. This also makes it easier to get used to the system and work with it, as all machines have it. Furthermore, more machine parts could be added to the dashboard to present the real-time RUL of them, as tools are not the only part that need maintenance. This ensures an even better preparation on the upcoming production planning.

Chapter 9 – Conclusion

At the end of this project, a conclusion can be drawn from all the work and research. At the beginning, the problem statement was set up, together with one main research question:

How can actionable feedback be provided for production managers to optimize the machine output in an ICT-based tool, to be integrated in EVI?

To get more background information, literature research, interviews and the state-of-the-art were conducted.

From these three techniques, three concept ideas were extracted: The weekly report, prescriptive maintenance and the Root Cause Analysis. It could be concluded that the prescriptive maintenance approach suits the best in this project, as it was the only idea that also looks forward on what to do and how to prepare for the upcoming production, which is the actionable feedback part of the project. Furthermore, the stakeholders involved in the project were identified.

Moving on to the specification phase, functional and non-functional requirements were set up for the concept idea, and Lo-Fi prototyping was done with the target audience to get more insights in their perspective, and what should be added or removed.

In the realisation phase, the concept idea is realised and turned into a functional, interactive dashboard in Figma. There is one main dashboard for the production manager, and a phone application for the operator.

To evaluate the dashboard, a functional and a non-functional evaluation is conducted. The functional evaluation was to see whether the dashboard meets the functional requirements, and if everything works as intended. The non-functional evaluation was to see how effective the dashboard would be, and if the customers from Voortman would actually use it.

In conclusion, after executing every step from the Creative Technology design process, the answer to the research question can be provided:

This has been done by successfully creating a dashboard which assists in maintenance management, it provides real-time information on the RUL of the tools that are in the machine, and gives notifications when the tool is reaching the end of its operational life. Furthermore, by presenting actionable feedback to the production manager on what action to take, unplanned maintenance will be prevented and tools will be changed before they break. To prepare even better for the upcoming production, information on the production planning is given, which tools the machine needs, how much these tools have to do, and what the RUL will be after a certain project is finished. This helps to ensure that the tools will last

throughout the project, or at least that the operator is close to the machine when a tool is about to break. Especially at night, when there are no people at the factory, the machines are still running. If a tool breaks at 1 am for example, it may result in unnecessary downtime of a few hours.
To optimize the machine output, the recommended actions have to be executed. That is why the production manager can communicate with the operator, to let him know what to do when.
Another feature in the dashboard that helps to manage the maintenance and eventually optimizes the machine output, is the planned maintenance checklist. These maintenance tasks can be checked of by the operator, which ensures a clear overview whether maintenance actions are done or not.

By integrating all these features in a clear, user-friendly dashboard for the production manager and the operator, that can be integrated within EVI, actionable feedback can be provided to them to optimize the machine output.

It can be concluded that after the user study, the prescriptive maintenance dashboard met most of its functional and non-functional requirements. Reasons for requirements that weren't met were mostly due to the limitations of the dashboard, which can be resolved in the future of this project. The goal of this project is partially successfully reached, namely to provide actionable feedback to the production manager which optimizes the machines output. The dashboard provides actionable feedback to the production manager, but it is not yet proven that it optimizes the machine output, as the dashboard does not use real-time data and could thus not be implemented. But by presenting this prescriptive maintenance dashboard, the research question is positively answered.

References

[1] Voortman Steel Machinery, [Online]. Available: https://www.voortman.net/nl/producten/machines. [Accessed 14 February 2024].

[2] "Next-generation steel workshop management," DIGI-Steel, [Online]. Available: https://www.digi-steel.com/nl/. [Accessed 5 July 2024].

[3] "Evocon," 17 July 2023. [Online]. Available: https://evocon.com/articles/cost-of-downtime-in-manufacturing-insights-implications/. [Accessed 28 February 2024].

[4] Voortman Steel Machinery, [Online]. Available: https://www.voortman.net/nl/producten/oplossingen/vacam-besturingssoftware. [Accessed 14 February 2024].

[5] Voortman Steel Machinery, [Online]. Available: https://careers.voortman.net/en/about-us. [Accessed 14 February 2024].

[6] "Craft," [Online]. Available: https://craft.co/voortman-steel-group/locations. [Accessed 14 February 2024].

[7] Voortman Steel Machinery, [Online]. Available: https://www.voortman.net/en/products/solutions/evi. [Accessed 14 Febuary 2024].

[8] X. Chen, *Application of data-driven models to predictive maintenance: Bearing wear prediction at TATA steel,* vol. 186, p. 11, 2021.

[9] Federal Steel Supply, [Online]. Available: https://www.fedsteel.com/insights/emerging-trends-in-the-steel-industry-for-2024/#:~:text=Sustainable%20practices%3A%20Steel%20companies%20are,to%20improved%20efficiency%20and%20quality.. [Accessed 2024 March 25].

[10] "SmartWire-DT intelligent wiring solution," Eaton, [Online]. Available: https://www.eaton.com/gb/en-gb/catalog/industrial-control--drives--automation---sensors/SmartWire-DTintelligentwiringsystem.html. [Accessed 12 April 2024].

[11] Fanuc, [Online]. Available: https://www.fanuc.co.jp/en/product/field/basic/index.html. [Accessed 25 March 2024].

[12] Cool Industries, [Online]. Available: wBhB3EiwAeJsppLA5tZln7QDEEWOjHfH3RBiI3mBIcjgSzQFOT99du. [Accessed 27 March 2024].

[13] TechTarget, [Online]. Available: https://www.techtarget.com/searcherp/definition/lean-production#:~:text=Lean%20manufacturing%20is%20a%20methodology,not%20willing%20to%20pay%20for.. [Accessed 27 March 2024].

[14] Kanban Zone, [Online]. Available: https://kanbanzone.com/resources/lean/toyota-production-system/andon/. [Accessed 27 March 2024].

[15] "APM Reliability," GE Vernova, [Online]. Available: https://www.ge.com/digital/sites/default/files/download_assets/apm-reliability-brochure_0.pdf. [Accessed 12 April 2024].

[16] "Aspen Mtell," [Online]. Available: file:///C:/Temp/AT-2103%20Aspen%20Mtell%20Brochure.pdf. [Accessed 12 April 2024].

[17] SAP, [Online]. Available: https://www.sap.com/netherlands/products/scm/industry-4-0/what-is-industry-4-0.html#:~:text=Industry%204.0%20kan%20worden%20gedefinieerd,data%2C%20robotica%20en%20automatisering%20omvatten.. [Accessed 23 March 2024].

[18] T. Zonta et al, "Predictive maintenance in the Industry 4.0: A systematic literature review," *ScienceDirect,* vol. 150, 2020.

[19] L. Antonazzo, D. Stroud and M. Weinel, "Smart manufacturing and tasks automation in the steel industry: Reflecting on routine work and skills in Industry 4.0," 2023.

[20] S. Vaidya, P. Ambad and S. Bhosle, "Industry 4.0 - A Glimpse," *Elsevier,* vol. 20, p. 238, 2018.

[21] I. Gerekli, T. Ziyad Celik and I. Bozkurt, "Industry 4.0 and Smart Production," *CEEOL,* no. 2, p. 7, 2021.

[22] B. Gajdzik and R. Wolniak, "Transitioning of Steel Producers to the Steelworks 4.0—Literature Review with Case Studies," *MDPI,* 2021.

[23] W. Nallaperuma, U. Ekanayake and R. Punchi-Manage, “Identifying factors that affect the downtime of a production process,” *Proceedings of the 15th Open University Research Sessions,* 2016.

[24] J. Liu, Q. Chang, G. Xiao and S. Biller, “The Costs of Downtime Incidents in Serial Multistage Manufacturing Systems,” *ASME,* p. 10, 2021.

[25] A. Shagluf, A. P. Longstaff and S. and Fletcher, “Maintenance Strategies to Reduce Downtime Due to Machine Positional Errors,” *Proceedings of Maintenance Performance Measurement and Management,* pp. 111-114, 2014.

[26] K. Matyas, T. Nemeth, K. Kovacs and R. Glawar, “A procedural approach for realizing prescriptive maintenance planning in manufacturing industries,” *ScienceDirect,* vol. 66, no. 1, pp. 461-464, 2017.

[27] A. Padovano, F. Longo, L. Nicoletti, L. Gazzaneo, A. Chiurco and S. Talarico, “A prescriptive maintenance system for intelligent production planning and,” *Elsevier,* vol. 104, pp. 1819-1824, 2021.

[28] P. Nunes, J. Santos and E. Rocha, “Challenges in predictive maintenance – A review,” *ScienceDirect,* vol. 40, pp. 53-67, 2023.

[29] F. Ansari, R. Glawar and T. Nemeth, “PriMa: a prescriptive maintenance model for cyber-physical production systems,” *TandF Online,* pp. 482-503, 2019.

[30] “CPPS,” Click Maint, [Online]. Available: https://www.clickmaint.com/glossary/cyber-physical-production-systems-cpps#:~:text=Cyber%2DPhysical%20Production%20Systems%20(CPPS)%20are%20industrial%20automation%20systems,software%2C%20networks%2C%20and%20databases.. [Accessed 10 April 2024].

[31] A. Mader and W. Eggink, ““A Design Process For Creative Technology”, Proceedings of the 16th International conference on engineering and product design education,” pp. 568-573, 2014.

[32] B. Kitch, “How to use the rolestorming brainstorming method,” Mural, 2 August 2023. [Online]. Available: https://www.mural.co/blog/rolestorming. [Accessed 15 May 2024].

[33] “Wat is de MoSCoW-methode?,” ICM, [Online]. Available: https://www.icm.nl/extra/wat-is-de-moscow-

methode/#:~:text=Het%20gebruik%20van%20de%20MoSCoW,en%20wat%20minder%20prioriteit%20heeft.. [Accessed 6 May 2024].

[34] “Understanding the MoSCoW prioritization,” Atlassian, 30 August 2023. [Online]. Available: https://community.atlassian.com/t5/App-Central/Understanding-the-MoSCoW-prioritization-How-to-implement-it-into/ba-p/2463999. [Accessed 6 May 2024].

[35] “Production Manager Job Description,” Workable, [Online]. Available: https://resources.workable.com/production-manager-job-description. [Accessed 5 July 2024].

[36] “What is Figma,” Figma, [Online]. Available: https://help.figma.com/hc/en-us/articles/14563969806359-What-is-Figma. [Accessed 11 July 2024].

[37] “Prescriptive maintenance dashboard,” [Online]. Available: https://www.figma.com/proto/LXJbEFUUfoCFD4DUWVh3AC/Prescriptive-maintenance-dashboard?node-id=17102-6781&t=12DPL8YCJevNBi3U-8&starting-point-node-id=17102%3A6781&scaling=scale-down&content-scaling=fixed&hide-ui=1. [Accessed 7 July 2024].

[38] “Technology Acceptance Model (TAM model),” UserSense, [Online]. Available: https://www.usersense.nl/kennisbank/usability-metrics/technology-acceptance-model-tam. [Accessed 6 June 2024].

[39] “Duurzaam staal blijft een traag verhaal,” ABN Amro, [Online]. Available: https://www.abnamro.com/research/nl/onze-research/duurzaam-staal-blijft-een-traag-verhaal. [Accessed 8 July 2024].

[40] [Online]. Available: https://resources.workable.com/production-manager-job-description.

Appendix A

Information letter in dutch, as all the interviewees were dutch:

Informatiebrief toestemmingsformulier

Algemene Informatie

Mijn naam is Thijs Rolleman en ik ben momenteel bezig met mijn afstudeeropdracht voor mijn bachelor Creative Technology bij Voortman Steel Machinery. Ik werk momenteel met de applicatie EVI, die inzicht geeft in de machine-output. Er is echter nog geen functie binnen EVI die actie onderneemt of advies geeft op basis van deze inzichten om de prestaties van de machine te optimaliseren. Dat brengt ons bij mijn onderzoek, namelijk het maken van een 'guide' dat Voortman klanten helpt om hun machine performance te optimaliseren.

Doel van het onderzoek

Het doel van dit onderzoek is om meer inzicht en kennis te krijgen in de machineprocessen en de machine-outputs, maar ook wat er veranderd kan worden om deze output te verbeteren. Ik hoop dit te bereiken door interviews af te nemen met mensen die expertise hebben op dit gebied, zoals machine-operators, EVI-ontwikkelaars of plant managers.

Setting

Voor het interview zal ik u vragen deze informatiebrief zorgvuldig door te lezen en verbaal consent te geven. Vervolgens zal ik enkele vragen stellen over de machines en de optimalisatie ervan. Dit zal ongeveer 5-10 minuten duren. Ik zal aantekeningen maken van de antwoorden die u geeft, maar het interview is anoniem en ik zal geen persoonlijk identificeerbare informatie verzamelen (zoals uw naam). Er is geen risico of voordeel verbonden aan deelname aan dit interview.

Intrekking

U kunt zich op elk moment terugtrekken uit het interview en bent dus niet verplicht om het interview af te ronden.

Persoonlijke informatie

In het interview wordt geen persoonlijke gegevens gebruikt. De enige gegevens die worden gebruikt, zijn de expertise van de deelnemer aan de studie.

Gegevensgebruik

De gegevens van dit onderzoek worden anoniem gebruikt in het onderzoek van dit afstudeerproject. Het doel van deze gegevens is om meer inzicht en kennis te krijgen in specifieke onderwerpen waar de deelnemer expertise in heeft.
De deelnemer kan tijdens de afstudeerfase contact opnemen met de onderzoeker om

toegang te krijgen tot de gegevens of vragen te stellen over de gegevens. Voorlopig zal de bewaartermijn van de data gelden tot het afstudeerproject volledig is afgerond. Daarna zijn de gegevens niet langer nodig en kunnen ze worden verwijderd.

Contactgegevens van de onderzoeker

Naam: Thijs Rolleman

E-mail: l.t.rolleman@student.utwente.nl

Telefoon: +31 6 31544058

Contact informatie voor vragen over je rechten als een deelnemer

Indien u vragen heeft over uw rechten als deelnemer, of informatie wenst te verkrijgen, vragen wilt stellen, of eventuele klachten over dit onderzoek met iemand anders dan de onderzoeker(s) wilt bespreken, neem dan contact op met de secretaris van de Ethiekcommissie Informatie & Computerwetenschappen: ethicscommittee-CIS@utwente.nl

Appendix B – Interview questions

Interview questions (General questions where I started with, along the interviews more questions where added based on the answers of the interviewee):

Production

1. What is your function within Voortman, and what are you working on the most?
2. Do you use or look at EVI, and how does EVI affect your work?
3. How do you describe the term ‘output’, as in from your perspective, what are KPIs (Key Performance Indicators) of the output?
4. What is already done to increase or optimize that output?
5. Do you have an idea how EVI can play a role in the optimization of the output?

Sales

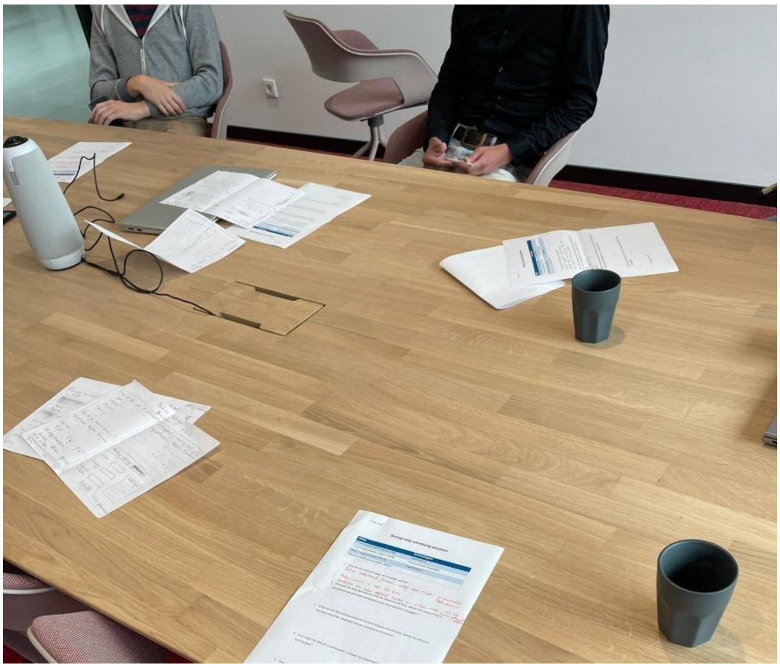
1. What is your function within Voortman, and what are you working on the most?
2. Do you use or look at EVI, and how does EVI affect your work?
3. What attracts customers, as in where do you focus on when offering or selling something to them?
4. How can we increase or optimize that, using EVI?
5. Do you have an idea how EVI can influence the output of customers?

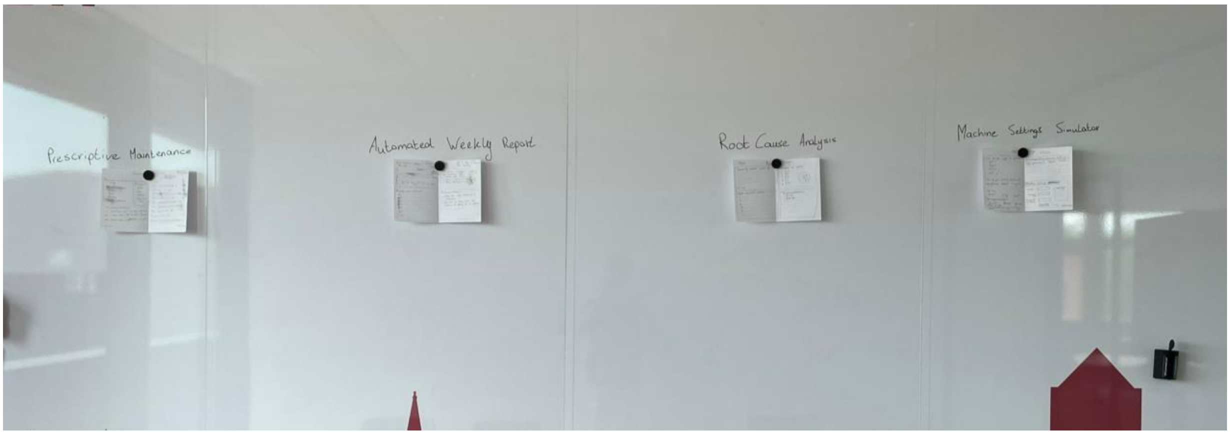
Appendix C – Group brainstorming questions & prototypes

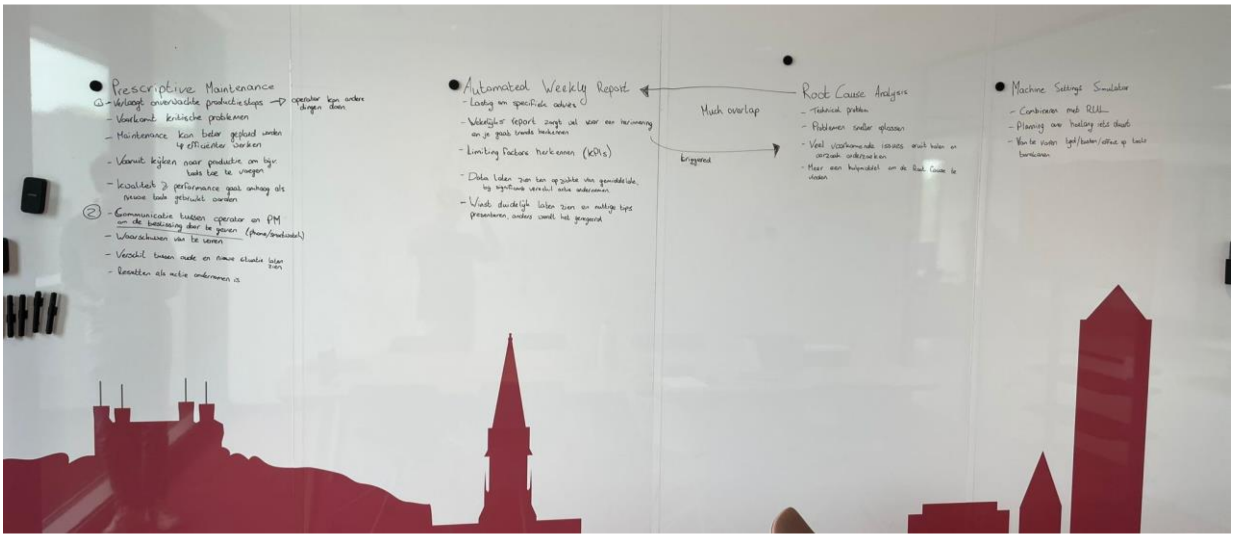
Group brainstorming questions for each technology (Dashboard, smart wearable/phone, gamification) with each idea (Automated weekly report, prescriptive maintenance, machine settings generator, and Root Cause Analysis):

1. How do you think the ideas/technologies can contribute to increasing the uptime?
2. What are the features/requirements the concepts should have, taking into account that it should provide actionable feedback to you (as production manager)?
3. What are the features/requirements the technologies should have, taking into account that it should be integrated into your working environment?
4. How might the idea (or a combination of ideas) be presented in the technologies?
5. How should it look?

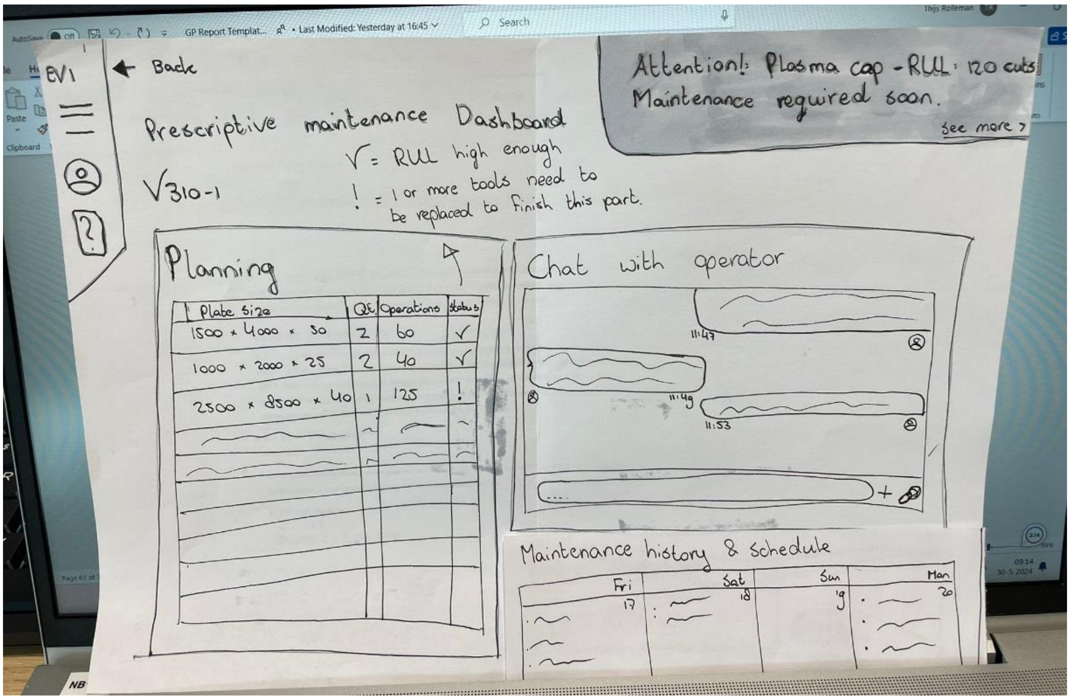
Results

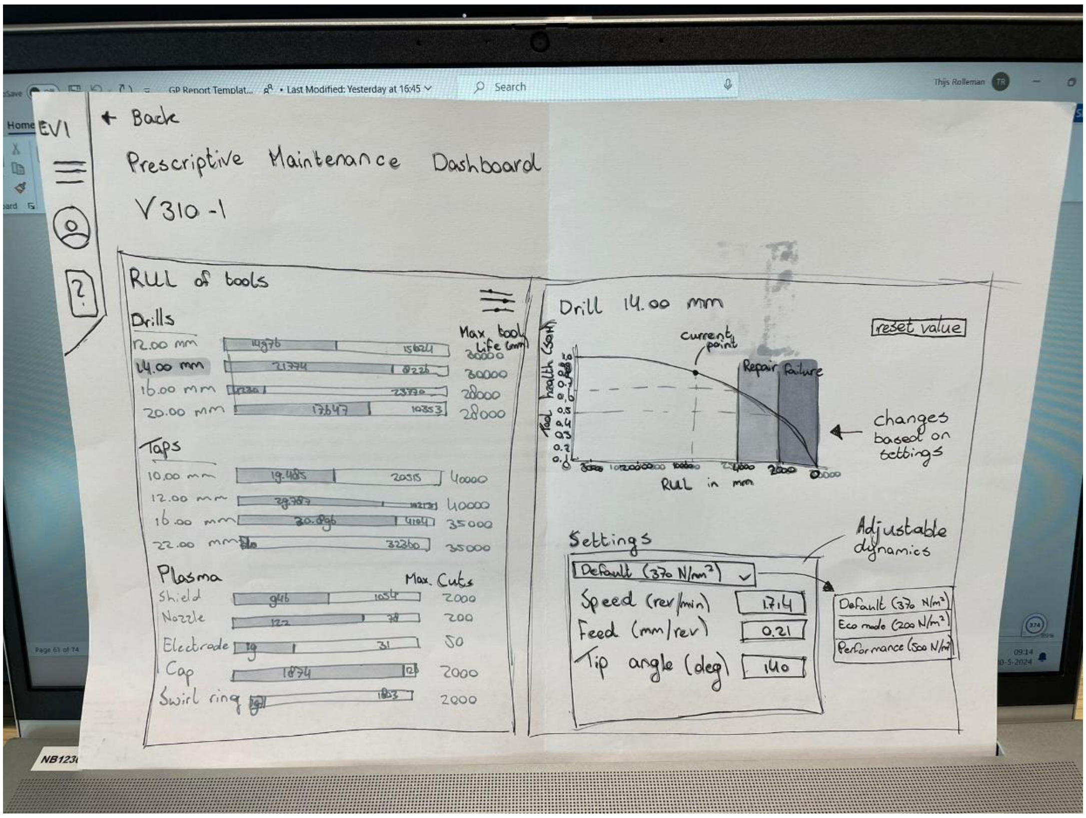


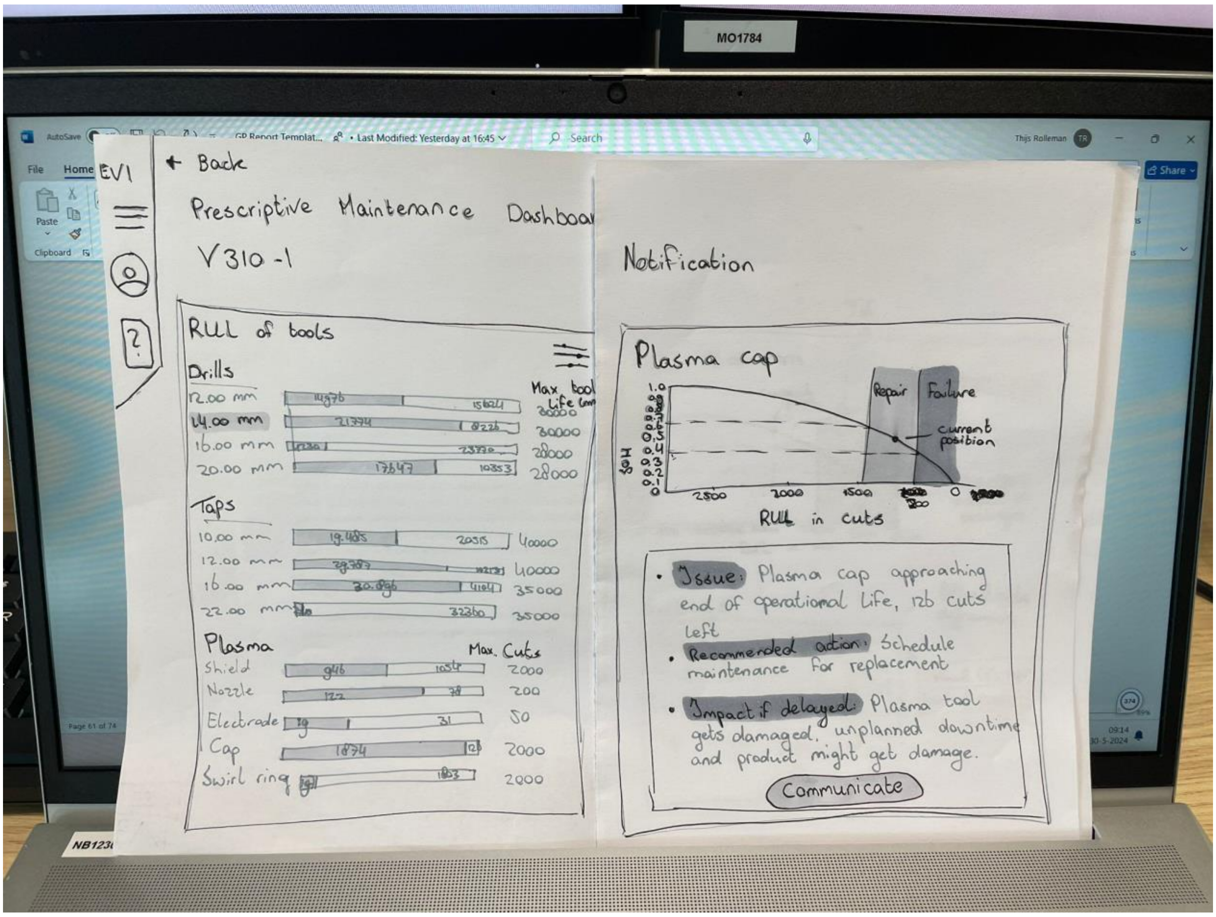

Prescriptive Maintenance
Automated Weekly Report
Root Cause Analysis
Machine Settings Simulator

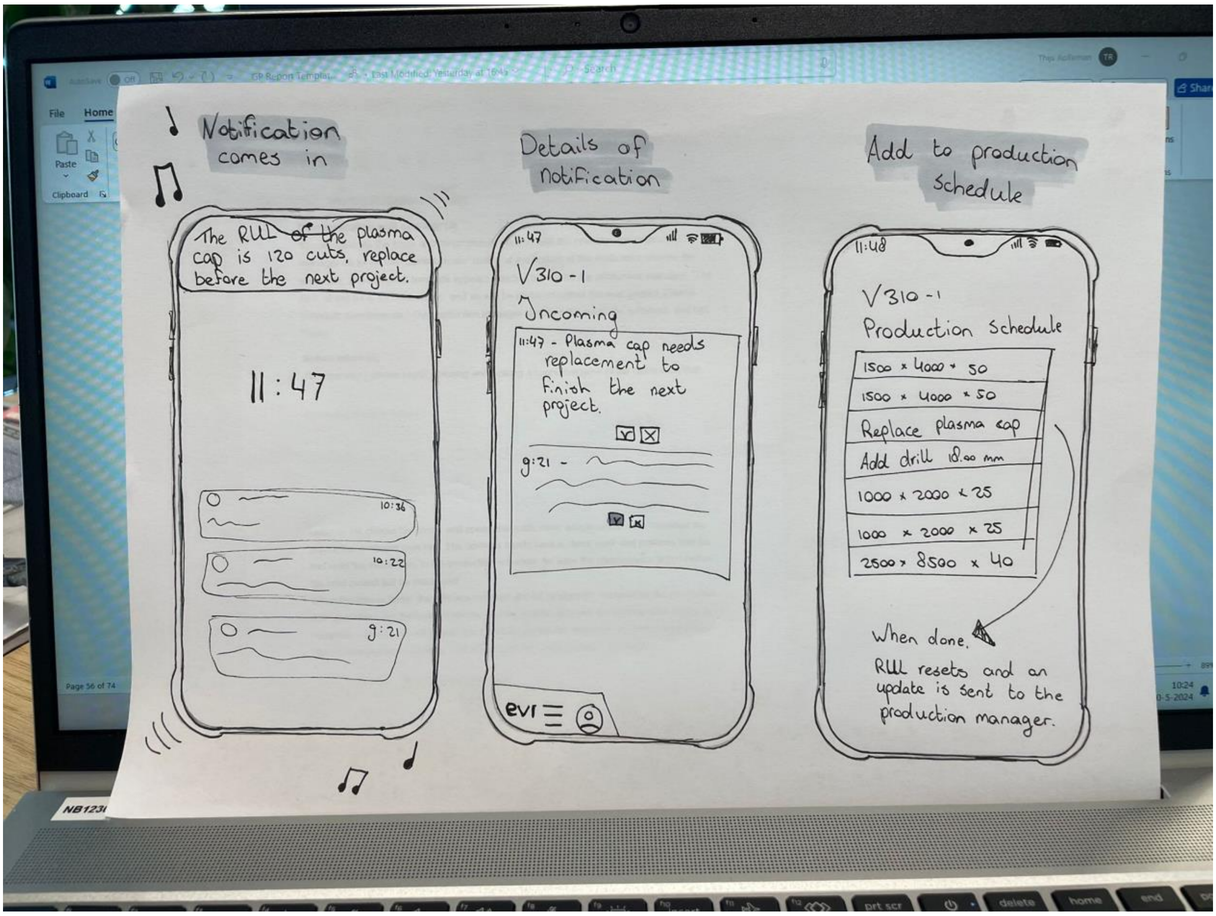

Prescriptive Maintenance
Automated Weekly Report
Much overlap
Root Cause Analysis
Machine Settings Simulator

Appendix D – Lo-Fi paper prototypes






EVI
Back
Prescriptive Maintenance Dashboard
V310-1
RUL of tools
Drills
Taps
Plasma
Max. Cuts
Notification
Plasma cap
Repair
Failure
current position
RUL in cuts
Issue: Plasma cap approaching end of operational life, 126 cuts left
Recommended action: Schedule maintenance for replacement
Impact if delayed: Plasma tool gets damaged, unplanned downtime and product might get damage.
Communicate


Notification comes in
The RUL of the plasma cap is 120 cuts, replace before the next project.
11:47
Details of notification
V310-1
Incoming
11:47 - Plasma cap needs replacement to finish the next project.
Add to production schedule
V310-1
Production Schedule
Replace plasma cap
When done, RUL resets and an update is sent to the production manager.

Appendix E – User-testing questions and results

Perceived Usefulness

1. Door dit product op mijn werk te gebruiken, zou ik taken sneller kunnen uitvoeren.
2. Het gebruik van dit product zou mijn prestaties op werk verbeteren.
3. Het gebruik van dit product zou de productiviteit verhogen.
4. Het gebruik van zou mijn effectiviteit op werk vergroten.
5. Het gebruik van dit product zou het makkelijker maken om mijn werk te doen.
6. Ik zou dit product nuttig vinden op werk.

Ease of use

7. Het leren omgaan met het product zou voor mij makkelijk zijn.
8. Ik zou het gemakkelijk vinden om het product te laten doen wat ik wil.
9. Mijn interactie met dit product zou duidelijk en soepel verlopen.
10. Ik zou dit product flexibel vinden om mee te werken.

Other questions

- Do you think this dashboard can contribute to increase the machine uptime, and if yes, how?
- What were things that you found interesting and necessary, and why?
- What were things that were unnecessary or that can be left out, and why?
- What are reasons that you (don't) want to use this dashboard in your daily work?
- What are reasons the operator (don't) want to use this dashboard in their daily work routine?
- What are your thoughts about the design and the looks?
- Is the dashboard intuitive? Why (not)?
- Do you think this dashboard can be a future feature of EVI?