Designing a Dashboard for the Shopfloor of a Manufacturing Company

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Preface

Dear reader,

In this paper you will read my bachelor thesis. My thesis assignment is commissioned by the Dutch software company Togetr. Togetr asked me to create a dashboard for their ERP system. This thesis explores how to create such a dashboard and how the dashboard can support the company. In this preface I want to give a special thank you to all those who supported me during the trajectory. I want to thank my supervisor Ipek Seyran Topan for guiding me during the thesis process. I want to thank her for the time she always had for the meetings and the valuable feedback she provided. I want to thank Hao Chen for being my second supervisor and reading through the paper and giving feedback. I also want to thank the supervisors at the company Togetr. They were always open for questions and gave valuable feedback. I also want to thank the company for the opportunity to do my bachelor assignment at Togetr. Thank you for welcoming me at Togetr in Veenendaal and treating me like a colleague. I gained a lot of new experience by working at a real company.

Kind regards,

Julia Timmerman

Management Summary

In this management summary we give an outline of the research project and its results. First, we begin with a small introduction about the assignment. Then, in the next section, we will summarize the problem with a motivation on why it has to be solved. Next, the main research question and research approach will be described. Finally, this management summary will conclude with the results and a recommendation. The thesis itself will go more in depth into each of sections with literature study and elaborate reasoning behind certain decisions.

Introduction

In this thesis assignment we will explore the function of a dashboard in decision making. The research is done at the company software company Togetr. Togetr is a Dutch company based in the Netherlands. Togetr has created an Enterprise resource planning (ERP) software that they call 'smart manufacturing platform' (SMP). The SMP supports companies in the manufacturing industry, for example support in supply chain management. The SMP has different modules, for example a finance module, a supply chain module but also a shopfloor module. Recently customers of Togetr have started asking about a shopfloor dashboard for in the shopfloor module. A shopfloor dashboard gives insight in processes that happen on the shopfloor of a factory. The shopfloor is the place where all production processes take place such as assembly of a mountainbike. A shopfloor dashboard is something that the ERP system does not yet have. The assignment from Togetr is to develop a shopfloor dashboard that can be integrated with their SMP system.

Problem and motivation

Like mentioned in the short introduction, customers have been asking for a dashboard, but Togetr cannot yet provide this in their SMP. This is a problem since not being able to provide a dashboard even though the demand is high, can lead into dissatisfaction from customers. This can be problematic since it could prevent potential new clients from signing a contract.

However, meeting customer demand is not the only motivation to solve the problem, because a dashboard can be very beneficial for both the clients and Togetr. A dashboard gives insight into data, it can for example show possible bottlenecks. With this insight, data-based decisions can be made and the bottleneck can be solved. The first step of solving a problem or bottleneck is being able to identify it and know that there is one.

One of the functionalities of the SMP is to create a planning once a production order is requested. With a dashboard, Togetr also has insight in the shopfloor operations of a client. This information could be used to improve the SMP. So, in conclusion, a shopfloor dashboard can be beneficial for both Togetr and the client.

Main research question

The main research question that we will answer in this thesis is: *'How can Togetr improve decision making for shopfloor operations by developing a dashboard?'* The problem owner in this research question is Togetr since the dashboard will be made for their system. So, this thesis will explore what the dashboard can do for Togetr.

Approach

To answer the research question and develop a dashboard, we had to take multiple steps. First, we had to analyse the current situation of Togetr to find out what they had already done regarding dashboarding. Then we conducted a literature study and interviews to explore what key performance indicators (KPIs) should be visualised in a shopfloor dashboard. Next, we had to select the KPIs and find out through literature study how to calculate and visualise them. Finally, the dashboard could be designed and evaluated.

Chosen KPIs

Based on literature studies and interviews, a list of shopfloor KPIs was created. However, this list had over 60 different KPIs, so the next step was to make a final selection. This was done by using a multi criteria decision analysis (MCDA) method. The highest ranking KPIs were chosen to be visualized in the dashboard. The Table 1 shows the selected KPIs with the chosen chart to visualize them. The charts are all available in Microsoft PowerBI. Microsoft also provides a description of when to use each chart, the decisions on the chart type have been based on this.

Table 1: Final chosen KPIs with visualization type

KPI	**Visualization**	**Reason**
OEE	Gauge chart	OEE is a single value measure. The OEE usually has a minimum value and a target value.
QBR	Card	The QBR is a single value that says something about the ratio of the good quantity.
NEE	Card	NEE is a single fact data point, it is similar to OEE.
SQ	Pie chart and line chart	SQ is visualized in a pie chart together with GQ. A pie chart shows a part to a whole. In one glance the proportions of good and scrap quantity can be seen.
SR	Card	SR is a percentage. A card makes it easy to read in one glance.
AHDO	Pie chart	Pie chart shows a part to a whole, so the proportions of hours spend on each operation can quickly be visualized.
AHDP	Pie chart	Pie chart shows a part to a whole, so the proportions of hours spend on each product can quickly be visualized.
TR	Card	The throughput rate is a single number, so on a card it is readable in one glance.
GQ	Pie chart and line chart	The SQ and GQ are also visualized in a line chart to display the trend over time.
CMR	Card	CMR is a single percentage. A card makes it easy to read in one glance.
MTTR	Card	MTTR is a single number value, a card makes it easy to read in one glance.

Table 1: Final chosen KPIs with visualization type

KPI	**Visualization**	**Reason**
PMT	Stacked column chart	PMT and CMT are visualized in a column chart. A column chart allows for easy visualization of a specific value across a category, in this case the maintenance time across time. A stacked column chart also allows to see the proportions of the corrective and preventive maintenance.
CMT	Stacked column chart	PMT and CMT are visualized in a column chart. A column chart allows for easy visualization of a specific value across a category, in this case the maintenance time across time. A stacked column chart also allows to see the proportions of the corrective and preventive maintenance.
MTOBF	Card	MTOBF is a average singe value. A card allows for easy reading of the number.

The KPIs have been visualized in PowerBI by using fictional data. This way client data was not needed.

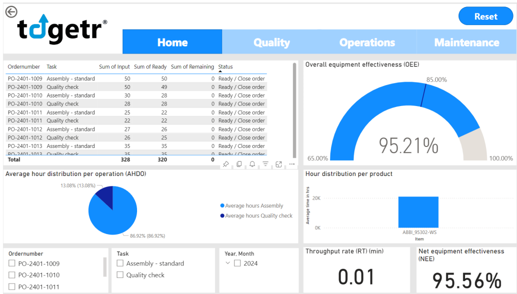
Results and recommendation

After we developed a first draft of the dashboard, the dashboard was evaluated by employees from Togetr and a client. With the feedback, we improved the first draft. Figure 1 shows the final dashboard.

The dashboard includes a home page (Figure 1(a)), which gives an general overview of the processes happening on the shopfloor. For example, it shows the 'overall equipment effectiveness' (EOO), which tells a user how efficient the processes happening on the shopfloor are. The home page also visualises how the time is distributed among the different processes and type of products. The dashboard also includes a quality page (Figure 1(b)). This page gives insight in quality related content. For example, it gives insight in the ratio of the good quantity and scrap quantity. Next, we also have a operations page (Figure 1(c). The operations interface mostly gives information about time efficiency of the processes. For example, in the first graph, we can see the estimated time compared to the actual time it took to complete an order. Finally, the dashboard also includes a maintenance page (Figure 1(d)). The maintenance page displays information about expected and unexpected maintenance.

With the dashboard, we have a few recommendations that Togetr could implement. The first is integrating the dashboard with the SMP so that real time data updates are possible. By doing this, an operations manager can analyse the data in real time.

A second suggestion is collect data that the SMP does not yet have. The dashboard is made with fictional data based on the SMP. However, in order to visualize all the suggested KPIs, some data has been made up. By visualizing these KPIs anyway, we have insight in why collecting the data might be useful. For example, the data used for the maintenance page in the dashboard is fully made up. However, insights in maintenance of machines can help make a more accurate planning



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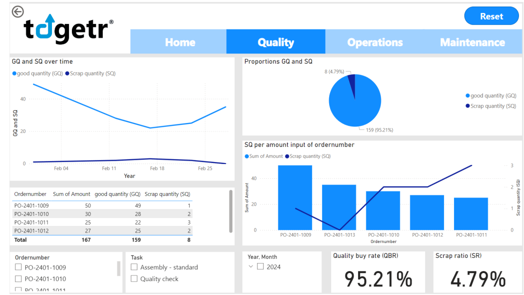

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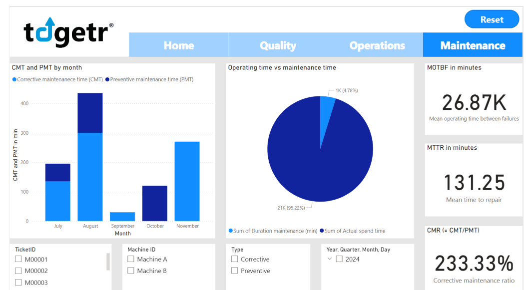

((d))

Figure 1: Dashboard with home page (a), quality page (b), operations page (c) and maintenance page (d)

since we can take into account expected maintenance time. With a more accurate planning, the Togetr software will be improved.

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1 Introduction

In this first chapter of the thesis we will give an introduction to the problem. In Section 1.1 the problem context is given, with a description of the company and the problem. In Section 1.2 we define the research questions with the accompanying knowledge problems. Finally, in Section 1.3 we will describe the chosen problem approach and research design.

1.1 The problem context

This thesis is in assignment of a company based in Veenendaal, the Netherlands, called Togetr. Togetr created an enterprise resource planning software (ERP), or also referred to as a smart manufacturing platform (SMP). This SMP is developed for high-tech companies in the manufacturing industry. The software, among other things, supports and automates production planning.

The SMP can be used by managers, but also by employees on the shopfloor. The SMP has different modules that each have their own roles. For example, there is a finance module in which an overview of invoices is given and outstanding payments. There is also a shopfloor module. This module gives information about the processes that happen on the shopfloor. The shopfloor is where all production processes of a company take place, it is essentially the factory floor. This shopfloor module can be used by operation managers to make decisions. However, it can also be used by employees, since the software also provides a planning of tasks. Each task that has to happen on the shopfloor has accompanying instruction book.

The SMP software is customizable to the clients needs, both in functionality and aesthetic. Some companies are more assembly focused, while others are production focused for example. Togetr developed the SMP in 2020, back then, the focus was on the functionality of the platform. Now, Togetr wants to keep on improving their software, one area they want to do that in is in data visibility. More frequently, customers ask Togetr for insight in data in the form of a dashboard. However, dashboard for the shopfloor of a manufacturing company is something that Togetr cannot yet provide. So, thesis will look into a approach of designing such dashboard that can support decision making.

1.1.1 Problem cluster

First is is important to exploit and define the problem before it can be solved. Figure 2 shows a problem cluster which visualises the core problems and action problems.

A lack of a dashboard leads to two problems: not being able to provide customers with a dashboard and inefficient decision making. The problem cluster in Figure 2 shows that all the problems can be traced back to having no visualization of data for the shopfloor module. Without visualization of data, there is no dashboard to present to the customers. This is a dissatisfier for customers since the demand for a dashboard is not being met by Togetr. This in turn could lead into loss of potential new clients. Customers want a dashboard since they want insight in data. Without insight in data, there is a difficulty in performance monitoring and identifying bottlenecks. This leads to unsupported decision making. This is why no visualization of data for the shopfloor module is chosen as the core problem. By solving the core problem, Togetr can present a dashboard to clients and help clients make data-based decisions for their shopfloor operations.

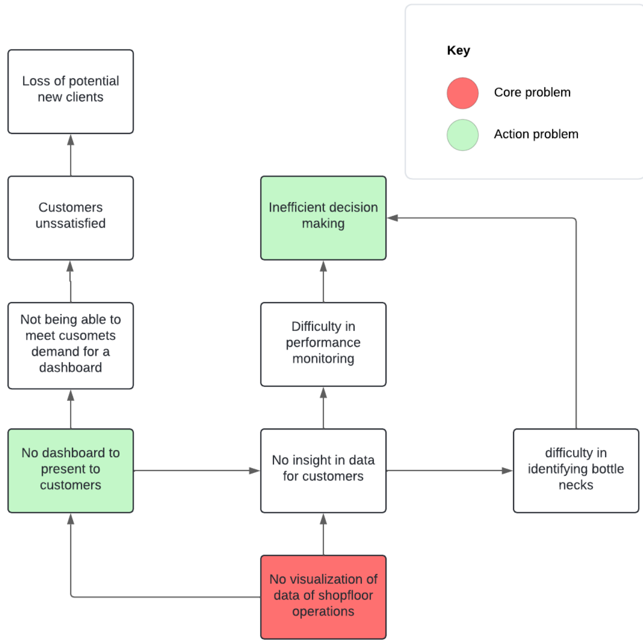


Figure 2: Problem cluster

1.1.2 The action problem

According to Heerkens, an action problem is a gap between norm and reality (van Winden and Heerkens, 2016). Therefore it is first important to identify the norm and reality. In summary, the norm is that Togetr should provide visualized data of shopfloor operations to customers. The reality is that they do not have a working dashboard to give insight in shopfloor data.

A dashboard is a decision support tool; with visualized data, it is easier to make data-based decisions. Having such a tool should be a norm for Togetr for multiple reasons. First of all, not providing a dashboard even though the customer asks for one is a dissatisfier for customers. This leads into delayed decision making for clients to accept the SMP which leads into sales contracts that take longer, possibly even canceled sales. Togetr could lose potential new customers. This also makes the urgent to solve the problem high.

Another reason has to do with decision making. Without visualized data of the shopfloor, it is harder for the clients to make data based decisions. It is also more difficult to identify hidden waste and bottlenecks. A dashboard could help make operational decisions to tackle the bottlenecks. Performance monitoring is essential for continuous improvement (Kaganski, Majak, Karjust, and Toompalu, 2017). A problem cannot be solved if it is not identified. Besides this being a benefit for the client, it also benefits Togetr: visualized data could give the company insight on what to improve in their software.

With the described norm and reality, we define the following action problem: The Togetr shopfloor module should be able to provide customers with visualized insight of data, currently Togetr does not have a dashboard to meet this demand.

1.2 The research question and knowledge problems

The main research question that is defined is related to the purpose of a dashboard. Like mentioned before, a dashboard provides insight in data of shopfloor operations. This can help companies identify bottlenecks and make data supported decisions. The problem cluster in Figure 2 shows that a lack of a dashboard could lead into inefficient decision making. Therefore, we formulate the following research question:

How can Togetr improve decision making for shopfloor operations by developing a dashboard?

To develop a dashboard for the shopfloor module, certain knowledge is needed beforehand. This information is gathered with the knowledge questions formulated below. These knowledge questions create a framework for conducting this research.

1. What does the current situation of the shopfloor module of Togetr look like?
   a. How does the shopfloor module process look like in the software?
   b. What has Togetr already done to visualize data in the shopfloor module?
2. What ker performance indicators (KPIs) should be visualized in a shopfloor dashboard?
   a. What KPIs do the clients of Togetr want to see in a dashboard?
   b. What KPIs does Togetr want to see in a dashboard?
   c. What KPIs are related to shopfloor operations in literature?
3. How to select a set of KPIs?
   a. What is the best way to choose a set of KPIs?
4. What data is needed to visualize the chosen KPIs?
   a. What data models are needed to calculate the KPIs?
   b. What data models does Togetr have available?
5. How can the chosen KPIs be visualized?
   a. Which visuals fits each chosen KPI the best?
6. How can the dashboard be implemented?
   a. What is the best way to present the dashboard to Togetr?
   b. What is the best way to present the dashboard to the clients?
7. How should the dashboard be evaluated?
   a. What are criteria of a 'good' dashboard?
   b. What are neutral questions to include in a survey to evaluate a dashboard?

1.3 The problem solving approach

One of the deliverables this research will provide is a decision-making tool in the form of a dashboard. This means that we create an artifact. An artifact, according to (Wieringa, 2014), "is something created by people for some practical purpose." This does not necessarily have to be something physical; it can also be software engineering (Wieringa, 2014). The decision-making tool will be an artifact, which means a design process is relevant for this case.

The design cycle that will be followed is the 'Design Science Research Methodology' (DSRM) according to (Peffers, Tuunanen, Rothenberger, and Chatterjee, 2007). In Figure 3 the process is visualized.

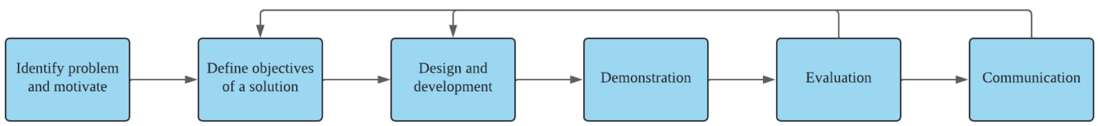


Figure 3: The DSPM according Ken Peffers, Tuure Tuunanen, Marcus A. Rothenberger, and Samir Chatterjee. A design science research methodology for information systems research. Journal of Management Information Systems, 24, 2007. pg 54

Identify problem and motivate

The first step of the process is to investigate the problem, the purpose of this is to show importance: why is a solution needed (Peffers et al., 2007)? The problem has already been identified in Section 1.1.

Define objectives of solution

The second step according to Peffers et al. (2007), is to define the objectives of the solution: what will the artifact achieve? Knowledge that is needed for this, is information about the current state. This knowledge is gathered by the first research question mentioned in Section 1.2: What does the current situation of the shopfloor module of Togetr look like? This question investigates what the Togetr shopfloor module in the software looks like, and what has already been done to tackle the problem.

Design and development

During this step the artifact is designed and developed. In order to design the artifact, or the dashboard, knowledge is needed on what is going to be visualized. This information is gathered by answering the second knowledge question: What KPIs should be visualized in a shopfloor dashboard? The sub questions investigate what KPIs the clients of Togetr want to see in a dashboard, what KPIs the company itself wants to see in a dashboard, and what KPIs literature suggests visualizing in a dashboard.

After we answered the second knowledge question, a set of KPIs is selected that will be visualized in the decision-making tool. The method of selecting the KPIs is done with an existing theory and or method. This is linked with knowledge question 3: How to select the KPIs? In order to visualize the KPIs in the dashboard, data is needed. Therefore, it is important to identify which data is needed and if this data is available. Knowledge question 4 needs to be answered for this: What data is needed to visualize the chosen KPIs?

Finally, for the design step, decisions need to be made on how to visualize the chosen KPIs. This decision is made with the knowledge on how each chosen KPIs can be represented the best. What type of graph or chart is suitable for example? This knowledge is gathered through research question 5: How can the chosen KPIs be visualized? By answering the above knowledge questions, we can design the artifact.

Demonstration

During this activity, the designed artifact is presented to the problem owner. The use of the dashboard is demonstrated. This step aligns with question 6: How can the dashboard be implemented?

Evaluation

The fifth step of the DSRM according to Peffers et al. (2007), is to evaluate the artifact. This is done by comparing the objectives to the results (Peffers et al., 2007). For the evaluation of the dashboard both the company and the company's customers are surveyed. Like mentioned in Section 1.1 and 1.2, there exists a demand for dashboards from clients. This means that the input from clients is important. It is up to the researcher to go back to the 'design and development' step of the process to improve the artifact based on the results of the evaluation. This step of the design process is parallel to the last knowledge question: How should the dashboard be evaluated?

Communication

This is the final step in the DSPM cycle. The communication of the importance of the artifact and the results are presented in this thesis paper. Also, the research will be presented during a colloquium.

Like mentioned before, in this research we follow the knowledge questions defined in Section 1.2. A detailed research design with the data gathering methods and plan of attacks can be found in Table 18 in the Appendix.

1.4 Conclusion

In this introduction we defined the problem and proposed a research approach. In the next few chapters, we will answer the sub questions formulated in Section 1.2. In the Chapter 2 we will describe the current situation in order to understand what Togetr has already done regarding visualisation and dashboarding. This chapter also contains an explanation of the SMP software to gain understanding of what Togetr actually does. The third chapter answers all the questions that need literature study, such as 'What KPIs are related to shopfloor operations in literature?' In Chapter 4 we will explore the whole design process of the dashboard, from selecting the KPIs to designing the interface. In the chapter 5, we will evaluate the dashboard and improve it with feedback received from different employees of Togetr. Finally in the last chapter, we will give recommendations based on the results and the developed dashboard.

2 The current situation

In this chapter we will answer the first knowledge question defined in Chapter 1: "*what does the current situation of the shopfloor module of Togetr look like?*" In Section 2.1 we describe how the shopfloor module in the Togetr SMP works. In Section 2.2 we will explain what Togetr has already done with dashboards and visualisation.

2.1 The software application: production orders

Like Chapter 1 describes, Togetr has developed a smart manufacturing platform (SMP). This enterprise recourse planning (ERP) application helps clients with manufacturing and supply chain planning processes. The application also has features with financing and hour registration. The basic processes of the application will be briefly explained. The feature that will be focused on is the production order planning, since this is relevant for the shopfloor. The purpose of this is to gain a better understanding of what the software tool does. This is important background information since the dashboard will be developed for a module in the software.

In the software, a customer of a company can create a production order. The software processes the information and creates a planning. Figure 4 visualises the basic steps of creating a production order. Each step in the process will be discussed briefly. The steps will be explained with an example: the production of a mountain bike. [1]

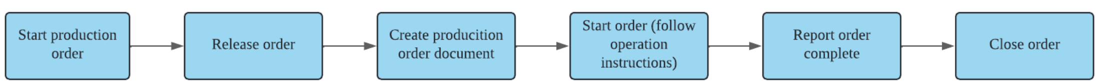


Figure 4: Production order process

Figure 5(a) shows that the process begins with starting a production order. The employee needs to fill in the following information:

- The article type
- The article number
- Amount that needs to be produced
- Destination warehouse
- The planning method (backwards or forward planning)

After the order is created, the order needs to be released. After that a order document can be made which shows the bill of materials (BOM) and the different operations that are needed to create the product. Figure 5(b) shows the main overview of the production order. It shows a list of tasks and information about the article. In this interface the order document can also be created. Figure 5(e) shows an example of a production order document. In the main overview a user can find the bill of materials (BOM) and the tasks that need to be completed (Figure 5(c)). Figure 5(d) shows a flow

[1]The screenshots of the software are partly in Dutch

of the operations that need to be completed for the specific order.

Now the order can be produced. For this the user goes to the 'operation support' this is the shopfloor module of the application. In Figure 5(f) the user can see the operations that need to be completed. The application shows if an operation can be started. An operation can start when all the materials are available and the previous operation has been completed. An operation can be started when both labels are green. When a shopfloor employee clicks on the operation, an overview of the operation with the needed materials pops up. Figure 5(g) shows this screen. For each operation, the working employee, can find a tutorial on how to perform the operation. The instruction book shows the steps the employee needs to follow. Figure 5(h) shows a tutorial page with a description of the steps and accompanying illustration. After the order is finished the employee reports the order as complete. Then the order can be closed

2.2 Current situation with visualisation

We conducted a unstructured interview with an employee of the implementation team to gain insight on what Togetr has currently done with the aspect of visualization and dashboards. An unstructured interview is exploratory, and does not necessarily have predetermined questions (Saunders, Philip, and Thornhill, 2019). This form of interview is chosen since the goal of the interview is to explore what Togetr has already undertaken with visualisation in their SMP.

2.2.1 Current situation: dashboards

The shopfloor module, or the manufacturing operation support (MOS) module of the SMP currently does not have any dashboards. The application does display certain data in the form of lists. Figure 5(f) shows an example of a list of remaining open orders.

The interviewed employee has been experimenting with user dashboards for clients. In one draft of a dashboard, a list of tasks and a agenda was visualized. This dashboard however, has not been officially developed. Also, the dashboard was not specifically focused on the shopfloor.

Another employee has been experimenting with developing dashboards in PowerBI, however, this was once again not for the shopfloor module. The dashboard the employee created in PowerBI is to give insight in process tracking of Togetr employees. For example, it compares the estimated hours of a task with the actual hours it took to complete.

In conclusion, Togetr has not yet done anything with developing a dashboard for the shopfloor module in the SMP.

2.2.2 Current situation: visualisation in the SMP

Though there is not yet a dashboard available in the software application, there are various features where visualization plays a roll. Visualization is a critical aspect of a dashboard. So, this is also an important aspect investigate to get a clear picture of the current situation.

One aspects of the application are tutorials for specific manual operations, for example the assembling of multiple parts. For this feature the different steps are shown in the tutorial accompanied

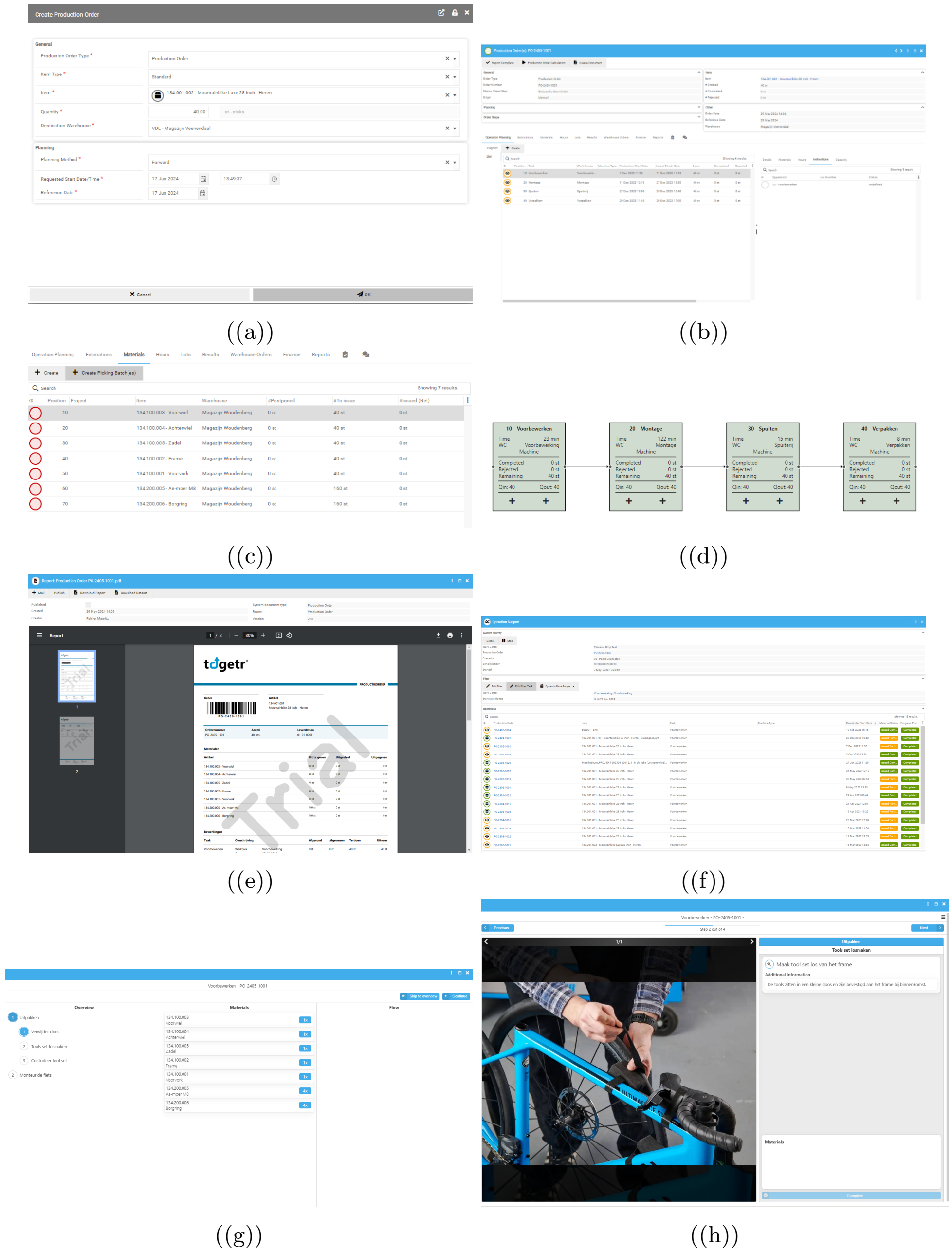


Figure 5: The shopfloor module with (a)'start production order,'(b) main overview of production order, (c) Bill of materials, (d) Operations flow, (e) Production document, (f) List of open operations, (g) Operation overview: preparation and (h) Tutorial.

with illustrations. This makes it easier for a factory employee to follow instructions. For an example see Figure 5(h).

There are also 'smaller' forms of visualisations supporting the different features of the SMP. For example, once a production order has been placed, a list is created with the remaining operations that need to take place. For each operation, two elements are shown. One element informs if all material is ready and the other if the previous task is completed. Both of these elements need to be green before the task can be started. This form of visualization is shown in figure .

Another example is a flowchart of the operations, which is shown in Figure 5(d). This visualizes the different steps and tasks that need to be completed for the final product. It also provides information about the quantities that are finished or remaining.

These different visualizations have the purpose to support the features of the ERP system. They add another level of user experience. The visuals also make the system more user friendly and attractive.

2.3 conclusion

In summary, Togetr has implemented different visualisation techniques to support the user experience in their software. However, nothing has been done yet regarding a shopfloor dashboard. Figure 4 describes the steps an operation manager can take in order to request a production order. Most of these steps take place in the shopfloor module of the software. In this module the dashboard will be implemented.

3 Literature study and background

This chapter contains all the literature research that supports the decisions and steps in this research. In this chapter we answers multiple questions that are described in Section 1.2. We will explore the following questions in order:

- What KPIs are related to shopfloor operations in literature? (Section 3.1)
- What is the best way to choose a set of KPIs? (Section 3.2)
- Which visualisation type fits each chosen KPI the best? (Section 3.3)
- How should the dashboard be evaluated? (Section 3.4)

3.1 KPIs and literature

During the preparation of the thesis, a systematic literature review (SLR) has been conducted to answer the following question *What KPIs are related to shopfloor operations in literature?*. This literature study resulted in a list of categorized KPIs. This Section summarizes the findings of the SLR. In Appendix A, a flowchart of the SLR can be found as well as a table with the main findings of the final sources.

Key performance indicators, or also known as KPIs are metrics that help track processes (Kaganski et al., 2017). The KPIs can be measured with data and expressed in numbers. KPIs can tell something about efficiency of a production machine for example. Monitoring these KPIs, is essential for performance improvement (Vasiljevic, Trkulja, and Danilovic, 2014). The performance metrics can help identify bottle necks and help achieve goals since KPIs can show a difference between the norm and reality (Varisco, Johnsson, Mejvik, Schiraldi, and Zhu, 2018).

To track process on the shop floor it is essential to monitor KPIs (Vasiljevic et al., 2014). The shop floor is the factory floor, it is the place where all operations take place: from manufacturing a part to assembling a machine. However, selecting the right KPIs has been proven difficult for companies (Kaganski et al., 2017).

The ISO (the international organization for standardization), has developed a list of 34 KPIs for manufacturing operation management (MOM), the document is called: 'ISO 22400-2:2014(en) Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions.' However, according to Kang, Zhao, Li, and Horst (2016), there exists relationships between the KPIs, they are not all independent. That is why Kang et al. (2016), created a hierarchical categorization of these KPIs. The KPIs are categorized in 'supporting metrics', 'basic KPIs' and 'comprehensive KPIs.' A visualization of the hierarchy can be found in Figure 6. 'Supporting metrics' is the data that is directly measured, which is time and quantity. Next there are 'basic KPIs,' these say something about either production, quality or maintenance. Finally, 'comprehensive KPIs' combine the basic KPIs, such as the comprehensive KPI overall equipment effectiveness (OEE). OEE is calculated by availability times effectiveness times quality (Kang et al., 2016).

The list of KPIs is specifically developed for manufacturing operations management, and therefore also useful for shopfloor operations. So, this list of KPIs answers the selected knowledge question. The list of the different metrics and categories according to Kang et al. (2016) can be found in Appendix C.

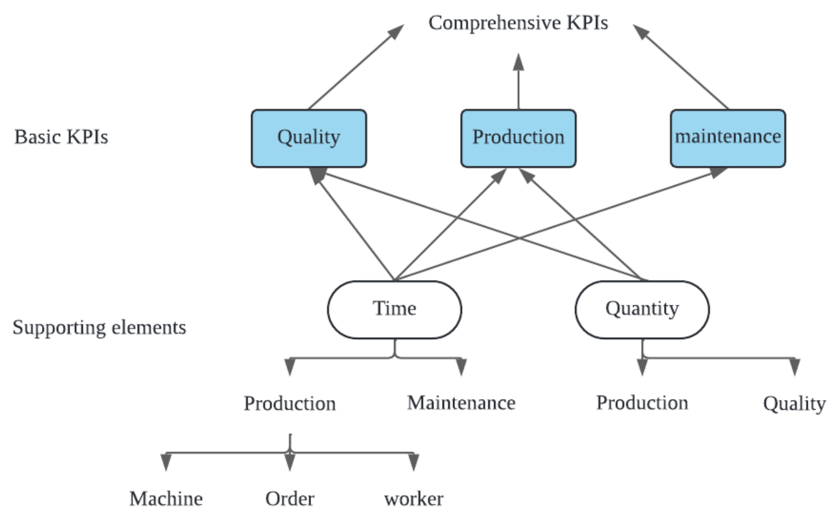


Figure 6: Hierarchy of KPIs according Ningxuan Kang, Cong Zhao, Jingshan Li, and John A. Horst. A hierarchical structure of key performance indicators for operation management and continuous improvement in production systems. International Journal of Production Research, 54, 2016. pg 3

3.2 Selection of KPIs

With a literature study the following knowledge question from section 2.2 will be answered: *What is the best way to choose a set of KPIs?* Different models are covered and discussed if they are suitable for this research. The final model that is selected is the analytic hierarchy process process (AHP) in combination with the technique for order preference by similarity to ideal solution (TOPSIS).

3.2.1 The KPI selection model

Kaganski et al. (2017) designed a KPI selection model that makes use of the enterprise analysis model (EAM). The EAM analyses and identifies bottlenecks within a company. Based on this, a set of KPIs can be selected. The EAM uses a questionnaire to identify the bottlenecks. Each question is asked twice with different formulations to make sure the answers are more reliable. If the answers of the different formulated questions are not the same, the questions are scrapped.

The 61 questions are answered based on a scale from 1 to 6, where 1 is strongly disagree and 6 is strongly agree. After the survey has been completed an analysis is done. First the reliability is described with the 'Cronbach's Alpha.' Next, the questions are ranked and the main issues are identified. Based on the issues, suitable KPIs can be selected.

This selection model is focused on selecting the right KPIs since it can be difficult to select the right metrics (Kaganski et al., 2017). Because of this, and the reliability check, it would seem like a relevant model to use to select the KPIs for the dashboard. However, the model is designed to select a specific set of KPIs for the weak spots of a specific company. The dashboard that will be designed in this research has to be applicable to multiple customers of Togetr, so this selection model would not be suitable. Furthermore in order for a survey to be reliable, a large sample size is needed. Which means that from various clients of Togetr, multiple people with different functions need to fill out the questionnaire. This is not realistic to achieve in the time for this thesis.

3.2.2 The MCDA

Multi-criteria decision making (MCDM) or multi-criteria decision analysis (MCDA) is a discipline that helps in decision making based on pre-determined criteria. There are different MCDM methods, but in the basis, they all follow the same steps (Abdel-Basset, Mohamed, Zaied, Gamal, and Smarandache, 2020). In literature, specifically in the database of Elsevier's Scopus, the amount of publications and citations has increased drastically for the combined search terms of performance indicators and MCDM (de Oliveira, de Oliveira, and Salomon, 2023). This makes it suitable to use a MCDM for this research.

One of the most used MCDM methods is the analytic hierarchy process (AHP). It is used in healthcare, maintenance, climate change but also in elections (Zyoud and Fuchs-Hanusch, 2017). It has also been used in selecting performance indicators, which is relevant for this research (de Oliveira et al., 2023). The method helps to prioritize criteria for the different alternatives that can be chosen. The AHP method was first introduced by Thomas L. Saaty. The first step in this process is to hierarchically structure the objective, the criteria and the alternatives (Saaty, 1990). Next, the criteria are ranked by pairwise comparison and finally a consistency verification is done. It is the verification that makes this method so advantageous (Ho, 2008).

So, to use the AHP, the following steps need to be followed according to Saaty (1990):

1. Define the hierarchical structure of the goal, criteria ad alternatives.
2. In a comparative decision matrix, rate the criteria.

Table 2: AHP criteria scale according to Saaty (1990)

Scale	Definition
1	Equal importance
3	Moderate importance over one another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
1/3, 1/5	Inverse scale

3. Normalize the matrix by dividing each value with the sum of its column. The sum of the normalised columns should equal 1.
4. Calculate the weighted criteria by taking the average per row.
5. Next, calculate the weighted sums per row.
6. Calculate the weighted sum ratio by dividing the weighted sum by the weighted criteria.
7. Calculate the eigen value λ by taking the average of the weighted sum ratio.
8. Next, calculate the consistency index with:

$$CI = \frac{\lambda - n}{n - 1} \tag{1}$$

With n = number of criteria

9. Calculate the consistency ratio (CR) by dividing the CI with a random value based on the number of criteria. If the CR is smaller than 0.10, the AHP can be assumed consistent and further calculations may be done.

Technique for order preference by similarity to ideal solution (TOPSIS), is also one of the most popular MCDM methods (Zyoud and Fuchs-Hanusch, 2017). Like the name hints, this methods ranks different alternative from most relevant to least relevant based on multiple criteria (Zyoud and Fuchs-Hanusch, 2017). Next to the ranking it also identifies the "the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Iswari, Arini, and Muslim, 2019)."Also, the computation can easily be done individually, so no advanced software is needed (Shih, Shyur, and Lee, 2007). The basic steps is to create a comparison matrix, implement the weights of the criteria and normalize the matrix, finally analyse the final ranking (Iswari et al., 2019).

The steps of TOPSIS are according to Tzeng and Huang (2011) who introduced the TOPSIS method. These steps are also followed by Wangdra, Hasachoo, and Sirisawat (2018) to rank KPIs for airport operations.

1. The first step is to make a comparison matrix and give values to the alternatives based on the predetermined criteria. The scale (Table 3) is taken over from Wangdra et al. (2018).

Table 3: Scale for KPI ranking

Scale	**Definition**
1	Not important
2	Less important
3	Medium important
4	Important
5	Very important

2. The second step is to normalize the matrix. This is done with the following formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{2}$$

where i are the rows, j the columns and x the original value.

3. The third step is to calculate the weighted normalised matrix. This is done by multiplying the value with the criteria weight.

4. Next the ideal best V+ and ideal worst V- are determined. These are the highest and lowest values of the criteria.

5. Finally the Euclidean distances from the ideal best and worst are calculated with the following equations:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \tag{3}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{4}$$

6. Finally, to make the ranking of the alternatives, the performance score, which is the distance from the ideal solution, is calculated with:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{5}$$

For this research, a combination of both methods will be used. First the AHP will be implemented to determine the weights of the chosen criteria. Next, TOPSIS will be applied to rank the different alternatives (in this case the KPIs). AHP is suitable since it makes use of a consistency verification, making it a reliable MCDM method. TOPSIS will be used because of the ranking and the user friendliness. The combination of AHP and TOPSIS is widely used (Zyoud and Fuchs-Hanusch, 2017). For example, it is used in is in the selection of performance indicators for airport operations (Wangdra et al., 2018).

3.3 Visualising the KPIs

The final step of the dashboard design is visualising the KPIs. For this, the choice needs to be made on what graphs or charts to use. It is important to know how to visualise the data, otherwise the visualisation might be misleading (Sedrakyan, Mannens, and Verbert, 2019). Also, the design is important, good dashboard design is crucial for communicating information clearly (Brath and Peters, 2004).

According to Malik (2013) there are four elements in dashboard design, these are:

- Color and graphics

- Choosing the right charts to visualise data
- Relevant animation
- Logical layout of content

The colors used in the dashboard should be simple, they should not be distracting. Choosing the right chart type is also important so that information is not misleading. When applicable animation should be relevant. Finally choosing a logical layout is important when designing a dashboard. For this it is crucial to select the right information to visualize, there should not be too many visuals in one dashboard. Malik (2013) recommends not using more than six windows.

Microsoft's PowerBI provides many options to visualise data. Microsoft also provided a guide on when to use each of the available visuals (N.A, 2024). The following graphics and information are all from the official Microsoft website (N.A, 2024). An overview of the visualisations is given in Table 4. Besides the graphs, PowerBI also has other types of visualisations. For example, a user can add images and text. Also, accompanying the visualisations slicers can be added to filter through data.

Table 4: Different types of visualisations

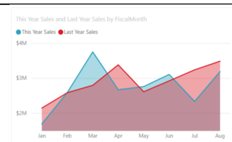
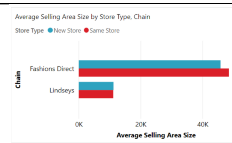
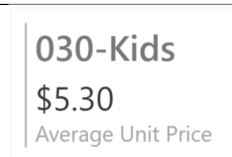
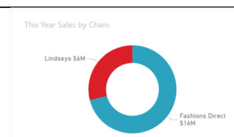
Visualisation type	**Example**	**When to use**
Area chart: basic (layered) and stacked		Area charts show the extent of a trend, usually over time. A stacked area chart also shows the total of different data series across a trend.
Bar and column		Bar and column charts showcase specific data values across categories.
Cards		For presenting single fact data points.
Combo chart (column and line chart)		Useful for when a column chart and a line chart share the same x-axis. It can be used to compare measures and show correlations.
Decomposition tree		Decomposition trees are useful for core problem analysis since it allows the user to visualize and drill down data across multiple dimensions.
Doughnut and pie chart		Pie charts (or doughnut charts with a blank in the middle) present a part of a total .

Table 4: Different types of visualisations

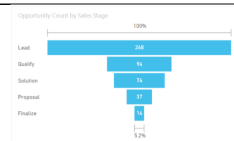
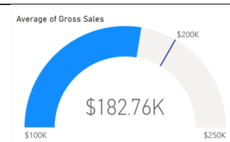
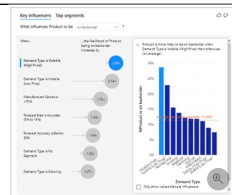
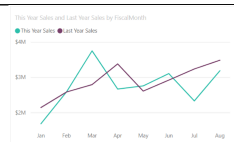
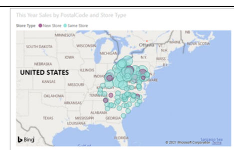
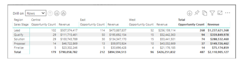
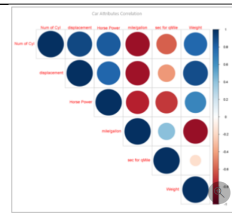
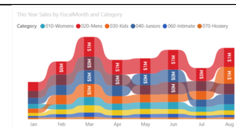
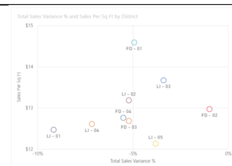
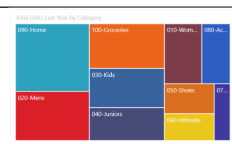
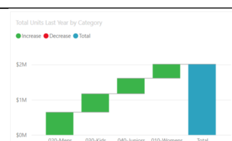
Visualisation type	**Example**	**When to use**
Funnel chart		Visualizes the item flow from one stage of the process to the next. It could help identify problems within a stage of the process.
Gause chart		Presents a single value measure from a minimum value towards a target value. Could be useful for visualizing KPIs.
Key influencer chart		Shows the major influences of a specific result or value.
KPI		Measures the progress and distance of a goal.
Line chart		Shows trend of values, usually over time.
Map		Display categorical and or quantitative data with specific locations.

Table 4: Different types of visualisations

Visualisation type	**Example**	**When to use**
Matrix and table		Tables can be used to display exact data values across different categories. Comparisons can be made without visualization. A matrix can display data across multiple dimensions. Also, a matrix allows a user to select multiple data points, rows or cells to drill down in the rest of the dashboard.
R - script		Can be created with R - script programming language. R script visuals provide advanced analysis tools to use with forecasting for example.
Ribbon chart		Ribbon charts can be used to display a ranking per category over a time period.
Scatter		Scatter plots show an intersection point of numerical data along the x - axis and the y - axis. It shows how numerical values from the axes might be related.
Tree maps		Treemaps show a hierarchy within data by the different sizes of rectangles; the bigger the value, the larger the rectangle. It also shows a part of a whole. Attributes can be highlighted with colors.
Waterfall chart		Shows a change of an initial value over time or categories. It also shows the running total. It can be used to see how certain values are positively or negatively influenced.

3.4 The user experience questionnaire

This paragraph answers the last question in the problem solving approach 'How should the dashboard be evaluated?' After the first draft of the dashboard is developed, the dashboard should be evaluated, then with the feedback improved. One way the dashboard could be evaluated is with a survey, according to Laugwitz, Held, and Schrepp (2008), questionnaires, 'allow an efficient quantitative measurement of product features.' With a questionnaire the dashboard could quickly be evaluated by multiple stakeholders, the employees of Togetr and their clients for example. Almasi, Bahaadinbeigy, Ahmadi, Sohrabei, and Rabiei (2023) conducted a literature study and suggests the following criteria on which a dashboard should be evaluated: 'usefulness, operability, learnability, ease of use, suitability for tasks, improvement of situational awareness, satisfaction, user interface, content, and system capabilities'.

Together with usability experts, Laugwitz et al. (2008) developed a survey to evaluate user experience: the user experience questionnaire. The user experience questionnaire (UEQ) is a widely used survey to evaluate user experience of a designed product. It measures attractiveness, perspicuity, efficiency, dependability, stimulation and novelty. The criteria are defined according to Schrepp (2019) as followed:

- Attractiveness: "Overall impression of the product. Do users like or dislike the product?"
- Perspicuity:"Is it easy to get familiar with the product? Is it easy to learn how to use the product?"
- Efficiency: "Can users solve their tasks without unnecessary effort?"
- Dependability: "Does the user feel in control of the interaction?"
- Stimulation: "Is it exciting and motivating to use the product?"
- Novelty: "Is the product innovative and creative? Does the product catch the interest of users?"

The survey is translated in more than 30 languages and, in 2023 there were more than 20, 000 users of the survey (Schrepp, 2019). The questionnaire consists of 26 statements which the participant grades on a 1 to 7 scale. The results can be transferred in an excel sheet. The results are then analysed based on the 6 criteria mentioned above. Also, a benchmark analysis is included to see how the product is user friendly compared to other products worldwide. To ensure reliability, a consistency check is also conducted in the analysis.

The dashboard evaluation criteria suggested by Almasi et al. (2023) correspond to the criteria that are measured in the UEQ designed by Schrepp (2019). The UEQ is also user friendly and widely used, making it a reliable survey. Therefore this questionnaire is suitable to use to evaluate the first draft of the dashboard.

3.5 Conclusion

In summary, this is how we answered the knoledge questions:

What KPIs are related to shopfloor operations in literature?
There are a lot of literature studies regarding shopfloor KPIs, in this thesis we will use a list of categorized KPIs by Kang et al. (2016). The list of KPIs is based on an official document from the international organisation of standardization (ISO) called 'ISO 22400-2:2014(en) Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions.'

What is the best way to choose a set of KPIs?
To make a final selection of KPIs we will apply two different MCDA methods. First we will apply the AHP to weigh criteria. Next we will use the criteria weights to make a KPI ranking using the TOPSIS method. Based on the ranking the KPIs can be selected.

Which visualisation type fits each chosen KPI the best?
Togetr requested Microsoft's PowerBi to be used for the dashboard development. Microsoft has a website providing describtions of each of the visualisation types that PowerBi offers. This guide will be used in order to choose a chart type for the KPIs.

How should the dashboard be evaluated?
For the evaluation we will use the 'user experience questionnaire' (UEQ). This is a official questionnaire used by thousands of studies to evaluate user experience. Based on the results of the questionnaire, the dashboard can be improved.

4 Designing the dashboard

In this chapter we develop the dashboard. For the development of the dashboard, we need answers on the knowledge questions defined in Chapter 1. *What KPIs should be visualized in a shopfloor dashboard?* After we gather all the KPIs, we need to know how to make a final selection of the KPIs. So the following question must be answered: *How to select a set of KPIs?*. Then, we need to know what data we need for the calculations: *What data is needed to visualize the chosen KPIs?* Finally, we need to make a choice on how we visualise the KPIs: *How can the chosen KPIs be visualized?*

4.1 The interviews

The interviews that will be conducted will be semi-structured. Semi-structured interviews do not have a standardized list of questions, but a list of themes and a few predetermined questions (Saunders et al., 2019). Because the interview is not standardized, there is room for other questions that might emerge during the interview (Saunders et al., 2019). This is suitable since the goal of the interview is to explore different preferences and opinions from different stakeholders. The future users of the dashboard are going to be Togetr and the customers of the Togetr. It is therefore important to take their preferences into account. For both the clients employees as well as the company's employees the same questions will be used about KPIs and dashboarding to ensure consistency. For the customer however, there will also be questions about the shopfloor. The interview setup can be found in Appendix B.

Before the start of the interview the purpose and relevance of the interview will be shared with the interviewee, as well as a time indication. When an employee finds the topic relevant, the employee is more likely to comply with the interview (Saunders et al., 2019). Also during the introduction of the interview, the contestants will be asked for consent for the recording of the interview. The contestant will also be asked about data privacy and til what degree they wished to be anatomized. For example, if it is okay to use the company name in the report.

4.1.1 Interview results: Togetr

Context for the interview

- Function interviewee: Architect for SMP (input for design and giving priorities on what needs to be developped. Also: Financial manager at Company X. (This company X is also a client of Togetr)
- The goal/use of (future) dashboard according to interviewee:
  - Management of company
  - Management of operations
  - Comparing company goals to output

Table 5 shows the KPIs and metrics that Togetr wants to see in a dashboard.

Table 5: KPIs from interview Togetr

KPI/metric	Abbreviation
Average issues in software	AIS
Throughput time	TPT
Amount of returns	AR
Invoice tardiness	IT
Actual credit use	ACU
Capacity	C
Average reminders for invoice	ARC
Reliability operation planning	ROP
Job satisfaction	JS
Average hour distribution operations	AHDO
Average hour distribution per product	AHDP
Reliability planning	RP
Scrap quantity	SQ
Overall equiment effectiveness	OEE

4.1.2 Interview results: The customer

Context for the interview:

- Function interviewee: manager of Company Y
- Type of company: Manufacturing company
- Shopfloor: Different stations of machines. Products are made on demand.
- Experience in dashboarding: manager has tried a few things in PowerBI from scratch. The indicators visualized in that dashboard are mostly about order intakes and finance.
- The goal/use of (future) dashboard according to manager: The dashboard will be used for monitoring operations on the shopfloor. It will be used for insight, not to reach a certain value of a KPI.

Table 6 shows the KPIs and metrics that Company Y wants to see in a dashboard:

4.2 Selecting the KPIs

After collecting the list if KPIs, we need to make a final selection. First, we remove all dublicates. Next the MCDA methods AHP and TOPSIS are applied. AHP is used to determine criteria weights. TOPSIS is used to make a ranking of the KPIs based on the criteria weights. The combined lists of KPIs can be found in Appendix G.

4.2.1 Criteria weights

The first step in the AHP is to create a hierarchy of the goal, the criteria and the alternatives (Saaty, 1990). In this case the goal is to choose a set of KPIs. The criteria are determined with

Table 6: KPIs from interview Company Y

KPI/metric	Abbriviation
Overall equipment effectiveness	OEE
Reliability planning	RP
Inventory value	IV
Revenue per year	R
Order intake per month	OIM
Ratio cost an inventory value	RCIV
Idle time machine	ITM
Availability	A
Average hour distribution operations	AHDO
Average hour distribution per product	AHDP
Inventory stock	IS
Avergage working hours per machine	AWH
Scrap quantity	SQ

an manager from Togetr since the dashboard will be for their ERP software. The criteria are the following:

- Cost related
- Time related
- Maintenance related
- Quality related

These criteria are chosen since a KPI, in general, can either say something about costs, time, maintenance or quality. The question is, which criteria should weigh more for a shopfloor dashboard.

At first, 'data availability', 'complexity of KPI' and 'relevance' were also included in the list. However, data availability is a prerequisite since data is needed to calculate the KPIs. The complexity criteria was also removed, since if a KPI is too complex to calculate within the given time it is removed. Also relevance is a prerequisite since the KPIs all need to say something about shopfloor operations, meaning KPIs that are not relevant to the shopfloor are immediately scrapped.

Next we compare the criteria pair-wisely in a matrix. The criteria is rated according to a predetermined scale. The scale that is used shown in Table 2 is the 1 to 9 scale according to Saaty (1990), who first introduced the AHP. The co-manager of Togetr was selected as decision maker, Table 7 shows the criteria ratings from the decision maker. After, we normalized the table by dividing each cell by the sum of the column. The weighted criteria is calculated by taking the average of the rows. Finally, to check if the scoring is consistent, we conducted a consistency check. First the ratings (Table 7) are multiplied by the criteria weights (Table 8). Then the weighted sum of the rows are calculated. Next, we calculate the ratio of the weighted sum and the criteria weights. Table 9 show the weighted criteria. After that the eigen value is calculated by taking the average of the previously mentioned ratio. With the lambda, the consistency index can be calculated.

Table 7: Ratings criteria

Criteria	**Cost**	**Time**	**Maintenance**	**Quality**
Cost	1	1/3	1/3	1/5
Time	3	1	3	1/2
Maintenance	3	1/3	1	1/3
Quality	5	2	3	1

Table 8: Normalised table and weighted criteria

Criteria	**Cost**	**Time**	**Maintenance**	**Quality**	**Weighted criteria**
Cost	0,0833	0,0909	0,0455	0,0984	0,0795
Time	0,2500	0,2727	0,4091	0,2459	0,2944
Maintenance	0,2500	0,0909	0,1364	0,1639	0,1603
Quality	0,4167	0,5455	0,4091	0,4918	0,4658
Sum	1,00	1,00	1,00	1,00	1,00

With the CI, we determine the consistency ratio (CR) by dividing the CI with a random number based on the number of criteria. For 4 criteria the random value is 0.90. The CR must be smaller than 0.10 for the AHP to be assumed consistent.

Table 9: Calculation ratio weighted sum

Criteria	**Cost**	**Time**	**Maintenance**	**Quality**	**Weighted sum**	**Ratio weighted sum/weights**
Cost	0,0795	0,0981	0,0534	0,0932	0,3242	4,0778
Time	0,2385	0,2944	0,4809	0,2329	1,2468	4,2345
Maintenance	0,2385	0,0981	0,1603	0,1553	0,6522	4,0688
Quality	0,3976	0,5889	0,4809	0,4658	1,9331	4,1505

$\lambda = (4,0778 + 4,2345 + 4,0688 + 4,1505)/4 = 4,133$
$CI = (4,133 - 4)/(4 - 1) = 0,0443$
$CR = 0,0443/0,90 = 0,0492$

$CR < 0,10$ so, the AHP can be assumed consistent and further calculation may be done with the final weighted criteria. Table 10 shows the final criteria weights, the table shows that the KPIs that say something about quality are the most important.

Table 10: Final weights of criteria

Final criteria	**Weights**
Cost	8%
Time	29%
Maintenance	16%
Quality	47%

4.2.2 Ranking the KPIs

After determining the criteria weights, the KPIs can be ranked using the TOPSIS method. However, first, from the list of KPIs that were gathered by the interviews and literature must be filtered. We filtered the list based on duplicates and irrelevant KPIs (KPIs not focussed on the shopfloor). The unfiltered list contains 85 KPIs and metrics. After removing the 8 duplicates, 77 remain. Finally, after scraping the irrelevant KPIs (for example metrics that say something about invoices and credit use), 71 remain as can be seen in Table 11.

Table 11: Filtered list of KPIs and metrics

KPI/metric	**Abbriviation**
Actual order execution time	AOET
Actual personnel attendance time	APAT
Actual personnel work time	APWT
Actual production time	APT
Actual queueing time	AQT
Actual to planned scrap ratio	SQR
Actual transportation time	ATT
Actual unit busy time	AUBT
Actual unit down time	ADOT
Actual unit idle time	AUIT
Actual unit processing time	AUPT
Actual unit setup time	AUST
Allocation efficiency	AE
Allocation ratio	AR
Amount of returns	AOR
Availabilty	A
Average hour distribution operations	AHDO
Average hour distribution per product	AHDP
Avergage working hours per machine	AWH
Blockage ratio	BL
Blocking time	BLT
Buffer capacity	B
Capacity	C
Corrective maintenance ratio	CMR
Corrective maintenance time	CMT
Effectiveness	E
Failure event	FE
Fall off ratio	FR
First time quality	FTQ
Good quantity	GQ
Idle time machine	ITM
Inventory stock	IS
Inventory value	IV
Line through put rate	LTR
Mean delay time	MDET

Table 11: Filtered list of KPIs and metrics

KPI/metric	**Abbriviation**
Mean operating time between failures	MOTBF
Mean time to failure	MTTF
Mean time to repair	MTTR
Meat setup time	MSET
Net equipment effectiveness	NEE
Operating time between failures	OTBF
Order intake per month	OIM
Overall equipment effectiveness	OEE
Planned busy time	PBT
Planned down time	PDOT
Planned operation time	POT
Planned order execution time	POET
Planned run time per item PRI	PRI
Planned scrap quantity	PSQ
Planned unit set up time	PUST
Preventive maintenance time	PMT
Processed quantity	PQ
Produced quantity in the first operation process	PQF
Production process ratio	PR
Quality buy rate	QBR
Ratio cost and inventory value	RCIV
Reliability operation planning	ROP
Reliability planning	RP
Rework quantity	RQ
Rework ratio	RR
Scarp ratio	SR
Scrap quantity	SQ
Set up ratio	SeR
Starvation ratio	ST
Starving time	STT
Technical efficiency	TE
Throughput rate	TR
Throughput time	TPT
Time to failure	TTF
Time to repair	TTR
Utilization efficiency	UE
Work in process	WIP
Worker efficiency	WE

With the scale in Table 3, we rate the KPIs in Table 12 to see how important the KPIs are for the criteria.

Table 12: Comparison matrix

KPI/criteria	Cost	Time	Maintenance	Quality
AOET	1	5	2	2
APAT	2	5	1	2
APWT	2	5	1	2
APT	1	5	2	2
AQT	1	5	2	1
SQR	2	1	2	5
ATT	1	5	2	1
AUBT	1	5	2	2
ADOT	2	4	5	3
AUIT	1	5	1	1
AUPT	1	5	2	1
AUST	1	5	2	1
AE	1	5	2	3
AR	1	5	2	3
AOR	2	2	3	4
A	2	4	2	2
AHDO	1	5	1	4
AHDP	1	5	1	4
BL	1	5	3	2
BLT	1	5	3	2
B	1	1	1	2
C	1	3	2	3
CMR	2	4	5	3
CMT	1	4	5	2
E	1	5	1	2
FE	2	3	5	3
FR	2	2	2	4
FTQ	1	1	2	5
GQ	1	1	1	5
IS	2	1	1	2
IV	4	3	1	1
LTR	1	5	3	3
MDET	1	5	4	3
MOTBF	1	5	3	2
MTTF	1	5	2	2
MTTR	1	5	4	3
MSET	1	5	2	2
NEE	1	5	3	4
OTBF	1	5	3	3
OIM	4	3	1	1
OEE	1	5	5	5
PBT	1	5	2	2
PDOT	1	5	3	2

Table 12: Comparison matrix

KPI/criteria	Cost	Time	Maintenance	Quality
POT	1	5	2	2
POET	1	5	2	2
PRI	1	5	1	1
PSQ	1	2	2	5
PUST	2	4	1	1
PMT	1	4	5	3
PQ	1	2	2	3
PQF	1	2	2	3
PR	1	5	3	3
QBR	2	2	2	5
RCIV	5	1	1	2
ROP	1	5	2	2
RP	2	5	2	2
RQ	1	2	2	4
RR	1	2	2	4
SR	1	2	2	5
SQ	1	2	2	5
SeR	2	5	2	2
ST	2	5	3	3
STT	2	5	3	3
TE	1	5	3	3
TR	1	5	1	4
TPT	1	5	1	2
TTF	1	5	2	2
TTR	1	5	4	3
UE	1	5	3	2
WIP	4	5	2	2
WE	2	5	1	2

The next step, as we defined in Section 3.2 is to normalise the ratings. We do this with formula 2. The normalized Table 20 can be found in Appendix H. After we normalised the matrix, we add the criteria weights which we determined with the AHP in Table 10.

With the weighted table we can calculate the ideal the ideal best and ideal worst solutions in Table 22. These are the highest and the lowest values of the criteria. Next, we calculate the Euclidean distances with the formulas 3 and 4. With the distances we can give each KPI a performance score with formula 5. The values of the Euclidean distances and performance scores can be found in Table 23 in Appendix H. Table 13 shows the ranking based on the performance scores.

Table 13: Final KPI ranking

KPI	Pi	Rank	KPI	Pi	Rank
OEE	0,7916	1	BL	0,3921	37

QBR	0,6713	2	BLT	0,3921	38
NEE	0,6680	3	MOTBF	0,3921	39
PSQ	0,6536	4	PDOT	0,3921	40
SR	0,6536	5	UE	0,3921	41
SQ	0,6536	6	RP	0,3806	42
SQR	0,6376	7	SeR	0,3806	43
FTQ	0,6233	8	AOET	0,3713	44
AHDO	0,6075	9	APT	0,3713	45
AHDP	0,6075	10	AUBT	0,3713	46
TR	0,6075	11	MTTF	0,3713	47
AOR	0,6070	12	MSET	0,3713	48
GQ	0,6018	13	PBT	0,3713	49
FR	0,5802	14	POT	0,3713	50
RQ	0,5638	15	POET	0,3713	51
RR	0,5638	16	ROP	0,3713	52
ADOT	0,5623	17	TTF	0,3713	53
CMR	0,5623	18	APAT	0,3652	54
MDET	0,5496	19	APWT	0,3652	55
MTTR	0,5496	20	WE	0,3652	56
TTR	0,5496	21	E	0,3566	57
PMT	0,5458	22	TPT	0,3566	58
ST	0,5430	23	A	0,3362	59
STT	0,5430	24	RCIV	0,2929	60
FE	0,5344	25	AQT	0,2900	61
LTR	0,5275	26	ATT	0,2900	62
OTBF	0,5275	27	AUPT	0,2900	63
PR	0,5275	28	AUST	0,2900	64
TE	0,5275	29	AUIT	0,2790	65
AE	0,5044	30	PRI	0,2790	66
AR	0,5044	31	PUST	0,2318	67
C	0,4446	32	IV	0,2226	68
PQ	0,4156	33	OIM	0,2226	69
PQF	0,4156	34	IS	0,2106	70
CMT	0,4111	35	B	0,2000	71
WIP	0,4080	36			

4.3 Final selection of KPIs

With the final ranking resulting from the multi criteria decision analysis, we can make a final selection of the KPIs. Like mentioned in the literature study, according to Malik (2013), there should not be more than six visuals on one page. However, a dashboard can have more than one page, so the final list of KPIs will not be limited to six. Also important to take into account is that some complex KPIs exist of basic metrics that are also higher ranking. These basic metrics could be used to calculate the complex KPIs, however the basic metrics might not be visualized in the dashboard by themselves. Furthermore, there might not be data available for the top ranking KPIs, therefore it is important to make a broad selection. Taking all of this into consideration, the KPIs with a performance score higher than 0,50 will be selected for the final list. This means the first 29 KPIs, the list with the formulas can be found in Appendix E.

In order to validate the final selection, we compared the list to the results from the interviews and literature study. We can see that there are multiple overlapping KPIs. For example, the top ranked KPI, OEE, is mentioned in both interviews and is also highly recommended by literature. Also, the AHDO and AHDP are mentioned in both interviews and are in the op ranking KPI list. This is evidence that the MCDM method used is reliable.

4.4 Data Cleaning

Before we can calculate the selected KPIs, we have to clean the received data. Togetr could not provide real data from clients due to privacy. Also, Togetr has not yet developed a way to translate their software data to PowerBI. So the data used for developing the dashboard is fictional. The fictional data is based on the SMP system, so it is data that Togetr would be able to provide. Some of the data we received is not yet something Togetr can provide. However in order to calculate the selected KPIs, the data was made up.

In order to be able to upload the excel sheets to PowerBI, the data needs to be in a collumnized format. The data was provided that way. Also, a few calculations needed to be made. For example, the total cycle time of an individual order from start to finish had to be calculated. This was needed to calculate the completion date since only the start date was provided. The cleaned up data has been added in Appendix D.

4.5 Measuring the KPIs

In order to easily calculate all the KPIs, we made an overview of all the formulas. In this overview, we also added the data that would be needed for the calculations. This overview is given in Appendix E. For most KPIs, the formulas can be found in the article from Kang et al. (2016) mentioned in Chapter 4. The formulas of the AHDO and AHDP are new KPIs based on the interviews.

The order of calculating the KPIs follow the hierarchical structure from Kang et al. (2016) (Figure 6). First the metrics are calculated if they are not provided by the data. Next, the basic KPIs are calculated with the metrics. Finally, the comprehensive KPIs can be calculated.

We make the calculations in PowerBi with the option 'add new measure.' We write the formulas in DAX code, which is the syntax of PoweBi. With this code we can reference the data sets that we uploaded in PowerBi. For an example, we calculate the comprehensive KPI overall equipment 'effectiveness'(OEE):

The formula of the OEE is the effectiveness times the availability times the quality buy rate:

$$OEE = E * A * QBR \tag{6}$$

In order to calculate the OEE, the effectiveness (E), availability (A) and the quality buy rate (QBR) need to be calculated.

$$E = ((PRI * PQ)/APT) * 100 \tag{7}$$

Where:

- PRI = planned runtime per item
- PQ = processed quantity (PQ = GQ + SQ + RQ)
- APT = actual production time

$$A = (APT/PBT) * 100 \tag{8}$$

Where:

- APT = actual production time
- PBT = planned busy time

$$QBR = ((GQ + RQ)/PQ) * 100 \tag{9}$$

Where:

- GQ = good quantity
- RQ = rework quantity
- PQ = processed quantity (PQ = GQ + SQ + RQ)

To make the calculations in PowerBi, we wrote the following DAX code:

1. The first step is to calculate the metrics from the data sets.

```
Planned run time per item (PRI) = SUM('Production Order Operation'[Cyclustijd])/COUNT('Production Orders'
[Ordernummer])
```

```
Processed quantity (PQ) = SUM('Production Orders'[Aantal])
```

```
Actual production time (APT) = (SUM('Production Order Operation'[Actual cyclustijd])/COUNT('Production
Orders'[Ordernummer]))*SUM('Production Orders'[Aantal])
```

```
Planned busy time (PBT) = [Planned run time per item (PRI)]*[Processed quantity (PQ)]
```

```
good quantity (GQ) = SUM('Production Orders'[Aantal])-SUM('Production Order Operation'[Scrap quantity])
```

2. Next, the basic KPIs can be calculated.

```
Effectiveness (E) = (([Planned run time per item (PRI)]*[Processed quantity (PQ)])/[Actual production
time (APT)])
```

```
Availability (A) = ([Actual production time (APT)]/[Planned busy time (PBT)])
```

```
Quality buy rate (QBR) = [good quantity (GQ)]/[Processed quantity (PQ)]
```

3. Finally, the OEE can be calculated.

```
Overall equipment effectiveness (OEE) = [Availability (A)]*[Effectiveness (E)]*[Quality buy rate (QBR)]
```

4.6 Design of the dashboard

The final step of the dashboard development is visualising the KPIs and designing the dashboard. Like found in the literature study, according to Malik (2013) there are four elements in dashboard design, these are:

- Color and graphics
- Choosing the right charts to visualise data
- Relevant animation
- Logical layout of content

Color and graphics

The colors in the dashboard should not be distracting and kept simple. Therefore, we choose Togetr's main color blue to give a company feel to the dashboard. The color is used to highlight important information such as a line in a graph. Text and captions are black for simplicity. Also, the company logo is displayed in the corner of the dashboard to add a customized element.

Choosing the right charts

It is important to know how to visualise the data, otherwise the visualisation might be misleading (Sedrakyan et al., 2019). For this, we need to choose what graphs or charts to use. In Chapter 3 in Table 4 we gave an overview of the charts that PowerBi offers and when to use them. Table 14 shows why and how each KPI is visualized. The charts are all from the official Microsoft website (N.A, 2024).

Table 14: Visualization choices

KPI	**Visualization**	**Reason**
OEE	Gauge chart	OEE is a single value measure. The OEE usually has a minimum value and a target value.
QBR	Card	The QBR is a single value that says something about the ratio of the good quantity.
NEE	Card	NEE is a single fact data point, it is similar to OEE.
SQ	Pie chart and line chart	SQ is visualized in a pie chart together with GQ. A pie chart shows a part to a whole. In one glance the proportions of good and scrap quantity can be seen.
SR	Card	SR is a percentage. A card makes it easy to read in one glance.
AHDO	Pie chart	Pie chart shows a part to a whole, so the proportions of hours spend on each operation can quickly be visualized.
AHDP	Pie chart	Pie chart shows a part to a whole, so the proportions of hours spend on each product can quickly be visualized.
TR	Card	The throughput rate is a single number, so on a card it is readable in one glance.

Table 14: Visualization choices

KPI	**Visualization**	**Reason**
GQ	Pie chart and line chart	The SQ and GQ are also visualized in a line chart to display the trend over time.
CMR	Card	CMR is a single percentage. A card makes it easy to read in one glance.
MTTR	Card	MTTR is a single number value, a card makes it easy to read in one glance.
PMT	Stacked column chart	PMT and CMT are visualized in a column chart. A column chart allows for easy visualization of a specific value across a category, in this case the maintenance time across time. A stacked column chart also allows to see the proportions of the corrective and preventive maintenance.
CMT	Stacked column chart	PMT and CMT are visualized in a column chart. A column chart allows for easy visualization of a specific value across a category, in this case the maintenance time across time. A stacked column chart also allows to see the proportions of the corrective and preventive maintenance.
MTOBF	Card	MTOBF is a average singe value. A card allows for easy reading of the number.

Next to the KPIs there is also other data that we visualized. On the home page for example, a table is shown with order numbers and their status. This is chosen to give an operation manager direct information if a certain order is completed. Also a funnel chart is added to visualise the items flowing from one operation to the other. Another table is created to show exact data about the good and scrap quantity of an order number. The reasoning behind the choices to add these extra visualisations is explained by the interpretation of the dashboard (this paragraph is focused on design choices).

Relevant animation

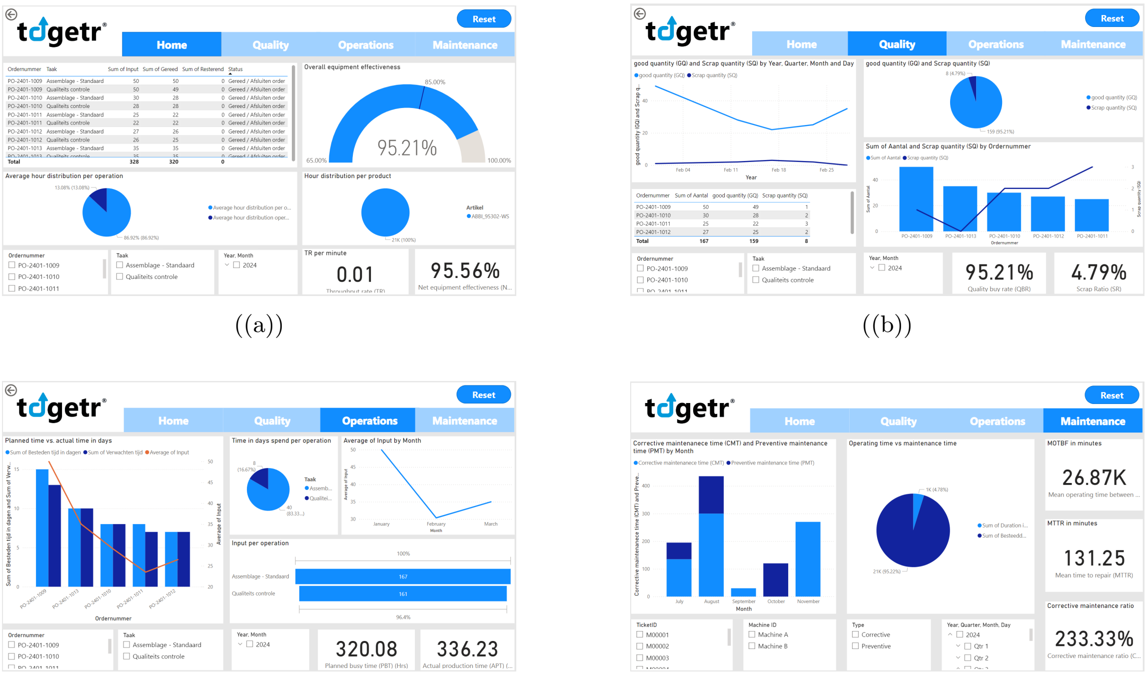
If a user wants specific information from the dashboard, the user can make use of the filters. A reset button is also added to quickly remove all the filters in one go. There are also different buttons to navigate to different pages. These animations are all practical.

Logical layout of content

According to Malik (2013), there should not be more than six visualisation panes that provide information. So, on each page of the dashboard we will not visualize no more than six KPIs. The pages of the dashboard are divided in a home page with general information and three other pages that are more specific. There is a quality page that gives insight in the quality of the products. Next, there is a operations page that provides insight about mostly the time efficiency of the operations. Finally there is a maintenance page that gives insight in maintenance operations. These pages are chosen since they overlap with the criteria in the MCDA. Costs are not included since the scope of the dashboard are shopfloor operations, financial information would be too broad.

4.7 First draft of the dashboard

Finally, after we calculated the KPIs and made graph choices we can develop the dashboard in PowerBi. Figure 7 is the first draft of the dashboard. Appendix I contains full sized screenshots of the dashboard. This section explains how to interpret the dashboard.



((a)) ((b)) ((c)) ((d))

Figure 7: First draft of the dashboard with (a) home page, (b) quality page, (c) operations page and (d) maintenance page

Home

The first page in the dashboard is the home page, Figure 7(a) shows the following elements:

- A table with the status of orders
- A gauge chart with the OEE
- A pie chart with the average hour distribution per operation
- A pie chart with the hour distribution per product
- A card with the throughput rate per minute
- A card with the NEE
- Filters
- Buttons to navigate

The home page is meant to give an operations manager, or other user, a quick general overview of the operations happening on the shopfloor of a manufacturing company. First, a table is shown to display exact data about order updates. This gives insight on what orders are completed per operation and which ones are being processed or still need to begin. Next, the OEE is displayed in a gauge chart. The OEE is a comprehensive KPI that says something about the overall efficiency of the whole shopfloor, therefore it is included in the home page (Kang et al., 2016). The fictional data is about a manufacturing company that focuses on assembly, so the OEE is technically not applicable. However, the goal is that the dashboard should be customizable for all kinds of clients Togetr might have. So one client might add the OEE in the dashboard and the other might not. It is included for now to present to Togetr how a dashboard might look like, also because the OEE was ranked as the number one KPI.

The home page also includes two pie charts about the hour distribution of the operations and of the products. This gives an operation manager insight on how the working hours are distributed in their shopfloor. If the hour distribution per operation is out of proportion it might hint to certain problems that could cause the 'too many' hours. The pie chart of the 'hour distribution per product is in this case one color. This is because the fictional data only had one product.

Next to the charts, the home page also has two cards to display single value data. First the throughput rate per (TR) minute is displayed on a card and second the net equipment effectiveness (NEE). Unlike the OEE, the NEE also includes the set up time (Kang et al., 2016).

Finally there are also filters en buttons added to enhance the user experience. The filters can be used to gain more specific information, for example the OEE in a specific year or month. To easily undo the selected filters, a user can click on the reset button. Furthermore, there are buttons to directly navigate to one of the other pages.

Quality

The next page is the quality page (Figure 7(b)). This page gives insight into the quality of the produced orders. In the MCDA the criteria 'quality' was rated the highest, that is why it is added as one of the first pages in the dashboard. This page has the following elements:

- Line chart of good quantity (GQ) and scrap quantity (SQ) per month
- Pie chart of proportions of GQ and SQ
- A table with exact data of GQ and SQ per order
- Combo-chart (bar and line) of total quantity and scrap quantity
- A card with the quality buy rate QBR
- A card with the scrap ratio
- Filters
- Buttons to navigate

The line chart gives insight of the trend of GQ and SQ over time. In this case of the fictional data, the user can see that around February 18th, the GQ went down while the SQ went up by a bit. This could mean that maintenance on a machine was needed or that the supplied materials might have been of lower quality for example. The pie chart shows the proportions of the GQ and SQ, a company would want the SQ to be as small as possible. The table shows exact data of the GQ and SQ per order. This information could tell how much extra needs to be produced to deliver the requested units to a customer. The combo chart of the bar and line chart shows the trend of scrap quantity per order and order quantity. This could show a potential correlation between the order quantity and the scrap quantity. Finally the cards show the QBR and the SR. The QBR shows how much percentage of the total quantity is good. This includes the rework quantity, however there was no data for this. The SR shows how much of the total quantity gets scrapped. The goal is to keep the QBR as high as possible. It is up to the company what the goal of the QBR should be.

Operations
Figure 7(c) is the 'operations' page. This page provides the user with information about the operations itself happening on the shopfloor. In the case of the fictional data, there are two different tasks that take place: the assembly and the quality check.

The operations page has the following elements:

- A combo-chart (bar and line) about the planned time vs. actual time.
- A pie chart of the time spend per operation.
- A line chart of the average input per month.
- A funnel chart about the items flowing from one operation to the next.
- A card with the planned busy time (PBT)
- A card with the actual production time (APT).
- Filters and buttons.

The first chart on this page is a combo-chart. The bar part in this chart show the difference between the estimated time and the actual time spend on completing an order. This can tell an operation manager about the reliability of the planning. If, for example, the actual time spend is constantly more than the estimated time, the estimated time should be adapted. A trend of input (amount of units ordered) is also shown in this chart to see if the workload and planned time vs. actual time spend is correlated.

The pie chart show the proportions of days spend on each operation (or task). While the home page shows an average distribution, this chart shows the actual distribution. The line chart shows the average input of orders per month, this could help with predictability of planned busy time. It is possible that during the month December for example, there might be less orders due to the holidays. The last chart is a funnel chart, like mentioned in Table 4, this chart shows the flow of items from one stage to the next. In this case, it can be seen that only 96.4 percent of the items end in the last stage while ideally it should be a hundred. A operations manager could now ask how this is possible and look for a possible bottle neck.

Finally this page displays two cards. One with the total PBT and one with the total APT. An operations manager would want these numbers to be as close to each other as possible. However, that is not likely since unexpected maintenance etc. could also happen. In this case it can be seen that the KPIs differ only with 16 hours, it can be concluded that the planning of this generally reliable. The first combo chart also proves this.

Maintenance
The final page is the maintenance page, which is shown in Figure 7(d). This page provides information about the machines. The data for this is made up by the supervisor later on so it is not related to the other data. It is added to show how the dashboard might look like with a maintenance page.

The page displays the following elements:

- A stacked bar chart of corrective maintenance (CMT) and preventive maintenance time (PMT).
- A pie chart of operating and maintenance time.
- A card with the mean operating time between failures (MOTBF).
- A card with the mean time to repair (MTTR).
- A card with the corrective maintenance ratio (CMR).
- Filters and buttons.

The first chart is a stacked bar chart that shows the CMT and PMT per month. It provides the operations manager how much time is spend on planned maintenance and unplanned (corrective) maintenance. Ideally, the PMT should be higher than the CMT since a manager takes PMT into consideration. In this case, the CMT is drastically more than the PMT, this could tell the operations manager to plan in more PMT or to possibly invest in new machines. The pie chart shows the proportions of operating time and maintenance time. Ideally the maintenance time should be kept as low as possible so that there is more time for operations.

This page has three cards that display single value data. First, there is the MOTBF, that is the average time that a machine can spend before a failure event takes place. By taking this number into account, a operations manager can be more precise with the planning. The same goes for the MTTR, this number can help plan in down time for the machine. Finally, the last card displays the CMR, this ratio is the CMT over PMT. The percentage should be as small as possible because that would mean that the PMT is larger than the CMT. Like mentioned before an operations manager would want the CMT to be as low as possible since that maintenance time is unforeseen. In the case of this dashboard, the CMR is too high.

4.8 Conclusion

In this chapter we explored the process of designing the dashboard. The dashboard is designed with the knowledge questions in the literature study, and the questions mentioned in the beginning of this chapter. After gathering KPIs from literature studies and interviews, the final list of KPIs was selected by using the MCDA techniques discussed in Chapter 3. Then, a visualisation type for each KPI was chosen. Finally the first draft of the dashboard could be developed.

5 Evaluation of the dashboard and a new design

In this chapter we describe the evaluation of the first draft of the dashboard. The dashboard is evaluated during a presentation to the company (the problem owner). The evaluation is the fifth step in Peffers et al. (2007)'s DSRM mentioned in the Chapter 1. For the evaluation the UEQ is used. Also, to receive feedback content related, participants of the survey have room to leave comments and points for improvement. In Section 5.1 we will talk about the results of the UEQ. In the following Section 5.2, we will talk about how the results and feedback are used for the improvement of the dashboard.

5.1 Results from the UEQ

After completing the first draft of the dashboard, it was presented to the Togetr during a monthly meeting. We presented the dashboard with a small explanation of the interpretation. After the presentation there was time for questions. Then, the widely used user experience questionnaire (UEQ) by Schrepp (2019) was filled in by those present in the meeting. The data of the survey was analysed in an excel sheet provided with the UEQ service. The questions and comments are organized in Table 15 below.

Table 15: Feedback and questions from survey participants

User interface/design	**Content related**
Make sure that all captions are visible on the charts.	Does the Togetr software have the data to create this dashboard?
Avoid double titles in charts (definition in title and in caption).	The OEE is visualized, but we also have a lot of clients that only focus on assembly, so how would the dashboard look for them?
For the reset button it might be nice to just use a refresh icon.	Is there data available for all this?
For the pie chart 'hour distribution per product,' what happens if a company has a lot of different products?	How will you take all different clients into consideration?

In total, six people filled out the questionnaire. The results were filled in the excel sheet provided with the UEQ. The excel sheet automatically makes calculations and transforms the results in the form of graphs so that it can be interpreted. Also, a consistency index has been calculated to find out if the UEQ is consistent.

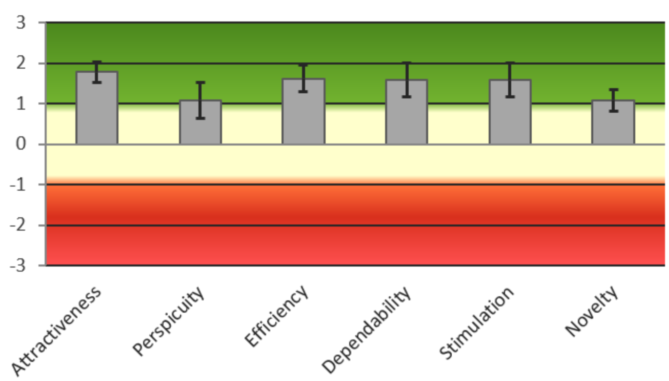


Figure 8: Results UEQ with confidence interval

In figure 8, we read the average scores on all the criteria described in Chapter 3. The 1 to 7 scale that is used in the questionnaire is translated to a -3 to 3 scale. The figure also presents a confidence interval with the lower and upper bounds of the ratings. Figure 8 shows that the dashboard scored the highest in the criteria 'attractiveness.' On average, the dashboard scored the lowest on 'perspicuity,' which says something about how easy the product is to learn (Schrepp, 2019). Next to 'perspicuity,' 'novelty' also scored lower compared to the other criteria.

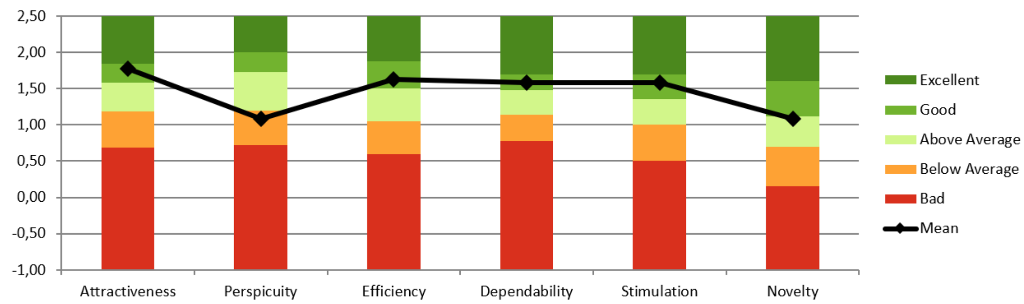


Figure 9: UEQ benchmark

Figure 9 shows the benchmark of the scores. The benchmark compares the results from the UEQ of this thesis, to the results of the UEQs of more than 20,000 users worldwide (Schrepp, 2019). According to Figure 9, the dashboard scores above average on attractiveness, efficiency, dependability and stimulation. However, 'perspicuity' scores below average.

In both Figure 8 and Figure 9 we see that 'perspicuity' scored the lowest. Like mentioned before, 'perspicuity' is how adaptable the product is, how easy it is to learn and understand (Schrepp, 2019)). Comparing the UEQ results to the feedback in Table 15, this could be because in the first draft:

- Not all captions and titles are visible.
- Sometimes the titles and captions provide the same information.
- English and Dutch is used interchangeably.

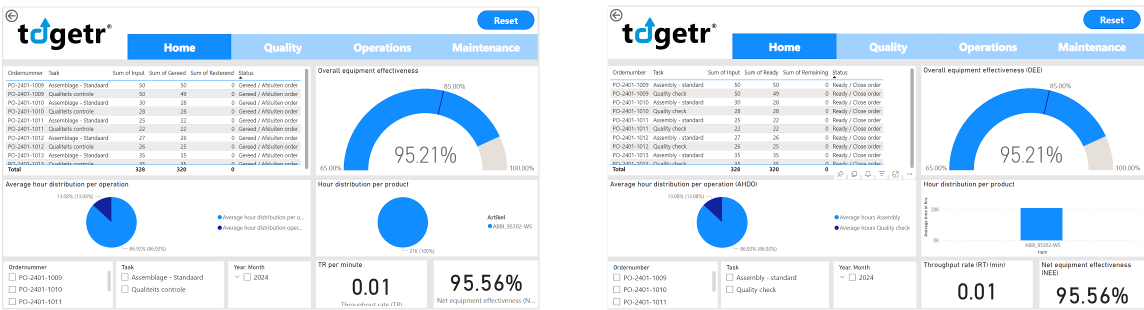
If the captions and titles of the charts and elements in the dashboard are not visible, it is harder to understand what a certain chart is about. When there is repetition of information in the titles and captions, there is no clear overview. This can also impact the 'perspicuity' in a negative way. Also, not being consistent in language influences the ease to understand the product. So, in the second draft, these points are the main focus for improvement.

By making sure the captions are visible and that there is no unnecessary double information, the dashboard will become more clear. Also, by making sure everything is in the same language, it will be easier to understand the product. By implementing this feedback, the dashboard could improve in 'perspicuity'; it will be easier to learn.

Novelty also scored a bit lower. However, according to the benchmark, it still scored above average. Novelty is about how innovative and new a product is (Schrepp, 2019). The concept of a shopfloor dashboard is not something new. Therefore, the changes will be focused on improving 'perspicuity.'

5.2 The revised dashboard

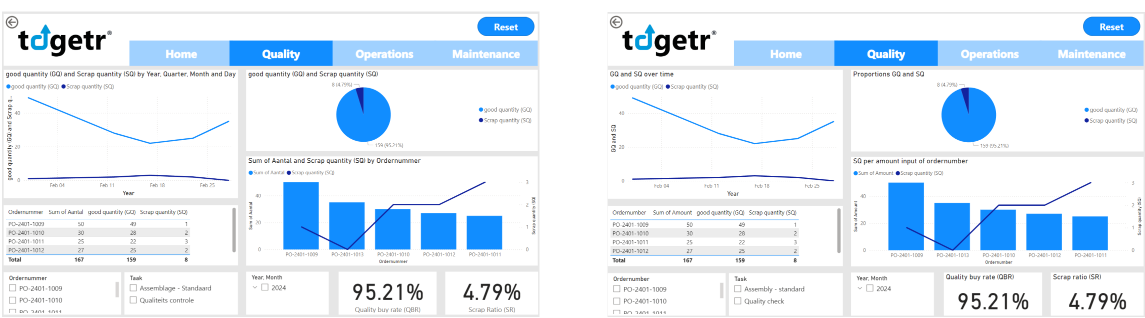
We improved the first draft of the dashboard based on the UEQ analysis and the received feedback. In this section we will compare the old and new dashboard pages with each other (full sized screenshots can be found in appendix J).



((a)) ((b))

Figure 10: Comparison of (a) first draft and (b) revised home page

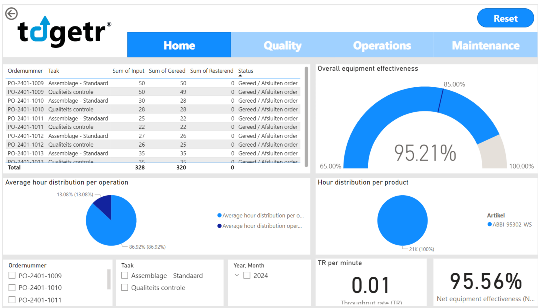
The most notable changes in the home page (Figure 10) are related to readability. First we can see that before (Figure 10(a)) not all captions were visible on the page, now in the revised version they are. Also, everything is changed to English, instead of a mix of English and Dutch. Finally the chart type for the KPI 'Hour distribution per product' is changed. First, a pie chart was used to represent the KPI. However, it is changed to a bar chart. This choice is made for a possible situation where there are multiple product types. If a company has a lot of products, a pie chart will be hard to read, while a bar chart will give a better overview in that case. These improvements are all based on the feedback received in Table 15.



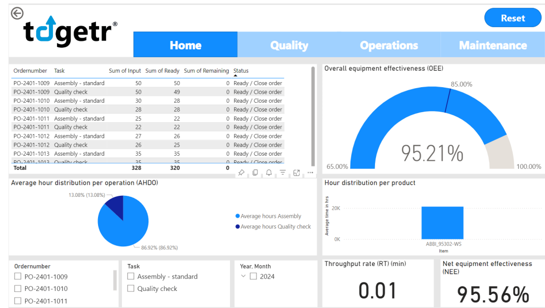
((a)) ((b))

Figure 11: Comparison of (a) first draft and (b) revised quality page

Figure 11 shows a comparison between the first draft of the quality page and the new one. For this page there are not any major changes made in chart types for example. However, once again the 'perspicuity' is improved by making the captions readable, making the language consistent and removing any repetition.

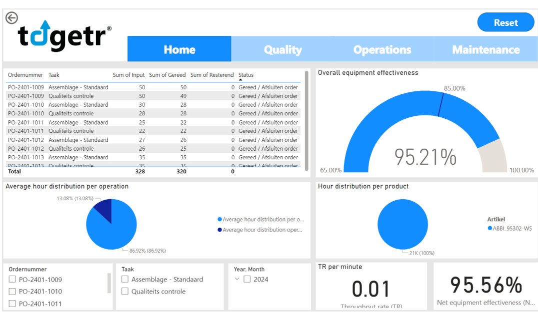


((a))

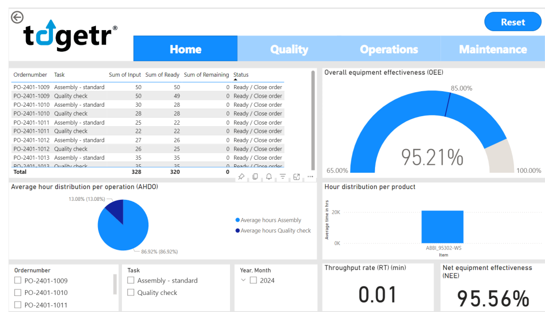


((b))

Figure 12: Comparison of (a) first draft and (b) revised operations page



((a))



((b))

Figure 13: Comparison of (a) first draft and (b) revised maintenance page

Figure 12 shows the original and new version of the operation page of the dashboard. Figure 13 displays the first draft and the revised version of the maintenance page. For both of these pages there are not any big changes made. The same changes mentioned above about 'perspicuity' are also implemented for these two pages. So, based on the feedback in Figure 15, the readability is improved by making sure that all the captions are readable and there is no repetition, and the language is changed into all English.

5.3 conclusion

In summary, based on the UEQ, most improvements are made on the criteria 'perspicuity,' which is the learnability of the dashbaord. Most of the feedback given by the respondents was also in line with this criteria, as can be seen in Figure 15. Based on this feedback the first draft is improved.

The most notable changes are that everything is changed to the same language, all captions are made visible and any repetition in titles and captions are removed.

6 Conclusion

The main research question of this bachelor assignment was: 'How can Togetr improve decision making for shopfloor operations by developing a dashboard?' The main users of the dashboard are going to be operation managers of client companies who make use of the Togetr ERP system. Another user is Togetr, the main problem owner in this research. Like mentioned in Chapter 1, Togetr should have a dashboard in their SMP for multiple reasons. First of all, there is a demand from the clients. This demand should be met, otherwise it could lead into a potential loss of customers. Another reason has to do with decision making. Without visualized data of the shopfloor, it is harder for the clients to make databased decisions. It is also more difficult to identify hidden waste and bottlenecks. A dashboard could help make operational decisions to tackle the bottlenecks. Performance monitoring is essential for continuous improvement (Kaganski et al., 2017). A problem cannot be solved if it is not identified. That being said, the client's problem is Togetr's problem. Besides this being a benefit for the client, it also benefits Togetr: visualized data could give the company insight on what to improve in their software. So how can Togetr benefit from their dashboard?

Based on the dashboard, we found multiple ways on how Togetr can improve their software. First, the developed dashboard gives insight in what data the smart manufacturing platform should collect and provide. The dashboard is based on KPIs selected from literature and interviews by using the MCDA. For some KPIs data was not available. However, since the data used was fictional, data could be added in the data set in consultation with the supervisor of Togetr. The visualised KPIs resulting from the MCDA gave new insights that were only possible with the fictional data. Based on this, there are new possibilities of data that Togetr can collect to improve their system. In Section 6.1, we further elaborate what data Togetr should collect and why.

Second, insight in the client's shopfloor operations can help Togetr make more accurate planning in their SMP. For example, the dashboard shows the CMR on the maintenance page. The CMR is the ratio of the CMT over the PMT. If the CMR is too high, an operation manager should plan in more maintenance time or perhaps invest in a new machine. One of the functions of the ERP software is that it makes a planning after an order request has been made. If the SMP would also collect data about PMT, the planning could be more accurate since maintenance time is taken into account. Another example of how the dashboard could help with operation planning is in the operations page of the dashboard. The combo graph (bar chart and line chart) shows estimated time an order would take and the actual time it took to complete the order. In two instances, the actual time was larger than the estimated time. In this case of the fictional data, the deviation is not that significant (also looking at the PBT and APT). However, if in a situation the actual time is consistently larger than the estimated time, it could mean that the planning should be improved. Also, the line graph 'average input per month' could show patterns over a long period of time. This could give information about busy seasons. This insight can help with forecasting and planning. To conclude, a more accurate planning will improve the functionality of the shopfloor module in the Togetr SMP.

So, the developed dashboard helps improve Togetr's shopfloor module by giving insight into what data to collect. Also, the insights provided by the dashboard can help Togetr make a more accurate planning. A more accurate planning will improve the functionality of the SMP.

6.1 Recommendations

In this section we give Togetr recommendations based on the dashboard we developed. First of all, we suggest to collect data that is currently not collected in the ERP system but what could provide interesting insights. For the dashboard we used fictional data, some of the data is not yet collected by the SMP system. This data was used anyways, to show the potential insights with the dashboard. The data that is not yet collected by the software is the following:

- Planned scrap quantity (PSQ)
- Rework quantity (RQ)
- Amount of returns
- Corrective maintenance time (CMT)
- Preventive maintenance time (PMT)
- Date of reported issue (for maintenance)
- Ticket ID maintenance
- Machine that needs maintenance

The system measures the scrap quantity (SQ). However, other interesting data might be the planned scrap quantity, which is how much scrap quantity a company expects to have when producing a product. This information could help with inventory management or in decisions to produce a bit extra as a buffer. The rework quantity (RQ)is also not measured in the current system. The RQ are the items that are not 'good' the first try but can be reworked or adjusted into good quantity (Kang et al., 2016). The RQ was needed for the dashboard in order to calculate the scrap ratio (SR), quality buy rate (QBR), processed quantity (PQ), produced quantity in first operation (PQF). In this case the RQ was left out in the calculations assuming the RQ included with the GQ. However adding the RQ would have made the calculations more precise. For example, in the quality page of the dashboard the proportions of GQ and SQ in the pie chart are the same as the percentages of the QBR and SR. With the RQ the percentages of the QBR and SR would be different. From the results of the MCDA, the amount of returns should also be calculated. The amount of returns is not yet measured but could be an indicator of the quality of the products. If a client is not satisfied with the products, there will be more returns for example.

There is also maintenance data that is not yet measured in the SMP. We recommend Togetr to measure some of this data since it can give interesting insights. The ERP system does not provide information about corrective maintenance time or preventive maintenance time (PMT). However, as seen in the dashboard interpretation, this could potentially be very valuable information. Taking account the PMT will make a more accurate planning. Furthermore, if the corrective maintenance ratio (CMR) is too high, as in the case of the dashboard, a company should consider planning in more PMT or to possibly invest in a new machine. The date of a reported issue is important to calculate the mean operating time between failures (MOTBF), this KPI is useful for planning in maintenance. The other elements mentioned in the list (ticket ID or machine that needs maintenance), are supporting information to organize and categorize maintenance data.

A second recommendation is to directly connect the dashboard to the SMP. With this, real time updates and insights are possible in the dashboard. This idea will be further discussed in 'future research.'

6.2 Ethics

In this research we had to consider multiple ethical related decisions. In one of the first stages of the research, interviews were conducted to receive input from Togetr and it's clients about shopfloor KPIs. Interviews can raise questions about possible privacy issues. Therefore, to ensure privacy, the interviewee was informed about the aim of the research and interview so the interviewee can make a honest decision to participate. Furthermore, the interviewee was asked if their answers could be used in the report and if they wanted to be anonymized. Both parties I interviewed (Togetr and 'Company X') wanted to be anonymized, the client also did not want the company name in the report, therefore the interviewed client is referred to as 'Company X.'Also the evaluation survey could possibly raise ethical questions about privacy. However, the participants did not need to fill in personal information, so they are completely anonymous.

Since we had to use data in order to develop the dashboard, questions about data privacy also played a roll. However, the data that was used in the development of the dashboard is fictional. So the data is not related to any real company. The report does contain information about Togetr and what the company does. This information is all information that can be found on their public website. Permission was also granted to add screenshots of the order request process in the system (the pictures in Figure 5).

Next to the research process, the final product, the dashboard could also have a social impact with possible ethical implications. The goal of the designed dashboard is to use it as a decision making tool. The dashboard will help give insight to data; this makes data monitoring easier. A dashboard can therefore help identify bottlenecks. Once identified, these bottlenecks could be attacked and solved. So, a dashboard helps with data supported decision making. Without insight to information, it is harder to pinpoint a problem that can be solved. To summarize, a dashboard provides data transparency. An ethical issue that might arise here, is the question of data security. Who has access to the dashboard? How is it ensured that access of the dashboard is only available for authorized people? Is the dashboard secured against cyber threats? The dashboard contains information on the performance of shopfloor operations of a specific company, it is important that this data is secured.

A dashboard can potentially help a company make better decisions to improve efficiency of an operation. However, it is important to not put efficiency as highest goal. Employees should not be 'milked out' for example. So it is important to find a balance in how efficient a process can be.

6.3 Limitations

The research has a few limitations concerning the development of the dashboard. First of all, the data available was fictional data. Fictional data is useful for testing, however, the fictional data also contained data that the ERP system cannot (yet) provide. Even though the goal of Togetr is to eventually embed the PowerBi dashboard into their ERP system. Furthermore, some of the fictional data did not completely make sense. The operational data (Appendix D) was focused on assembly, without machines. However, the maintenance data was about two different machines. This caused some inconsistency in the dashboard. The purpose of this assignment was partially to show how a dashboard might possibly look like, so for a first draft the most important thing was to show *what* should be visualised in such a dashboard. This means that the two data sets (operations and maintenance) not being related was not the biggest deal, but it would have been neater if the data was consistent. That is also why the OEE is visualised even though the fictional data is about assembly. Also, the data that was available for creating the dashboard was very little (about 4 to 8 rows per sheet), which made making interesting analysis difficult.

Another element that limited the research is that only one client was interviewed. Togetr has multiple clients that work in the manufacturing industry. However, some company's are more focused on assembly while the other is focused on production. Interviewing different types of clients might have led to different input which would have made the results more reliable since the dashboard should be applicable for both types. However, in the available time, it was difficult to make appointments.

The research would also be more reliable if we did a second UEQ for the final draft. Based on the first UEQ we improved the first draft. However, in order to measure if there was actually improvement, we should have conducted a second survey.

Finally, another possible limitation is the fact that during the second part of the MCDA (the TOPSIS), there was one decision maker. The decision maker was a co-manager at Togetr. This person might have different views on what is important than an operation manager for example. So, by including more decision makers and taking the average of the weights of each of them, the MCDA might have been more accurate in presenting a solution applicable to multiple stakeholder's needs.

6.4 Future research

If another student would have to continue this bachelor assignment there are multiple points for possible further research. First, we recommend to test the dashboard with real data and integrate the dashboard with the SMP system. With this feature the user of the dashboard is always up to date with the latest changes and real time data analysis would be possible. For this it is first important to generate the data in the right format for in PowerBi.

Another interesting future project might be to add a customisable feature where clients can select the KPIs they want to visualise based on the data they have available (for example, a company that does only assembly by hand will not use the OEE). To do this, more in depth client research would need to be done in order to get an idea of the different types of client's needs. The customizeable option would allow the dashboard to be applicable for all kinds of situations and would add another level of user experience. For this project it would also be interesting to include multiple decision makers in the MCDA in order to make the final list of KPIs more accurate.

6.5 Contribution to theory and practice

With this research project we have not necessarily contributed something new to theory. However, this assignment did contribute in practice. We designed a dashboard focused on the shopfloor, applicable for multiple companies. It adds a new dimension to the Togetr SMP. First the focus was on functionality, now a new level has been added: data visibility. The dashboard is designed for the client. However, as we have shown in the conclusion, Togetr can also profit from the dashboard.

Bibliography

References

Visualization types in power bi, 5 2024. URL https://learn.microsoft.com/en-us/power-bi/visuals/power-bi-visualization-types-for-reports-and-q-and-a.

Mohamed Abdel-Basset, Rehab Mohamed, Abd El Nasser H. Zaied, Abduallah Gamal, and Florentin Smarandache. Solving the supply chain problem using the best-worst method based on a novel plithogenic model. *Optimization Theory Based on Neutrosophic and Plithogenic Sets*, pages 1–19, 1 2020. 10.1016/B978-0-12-819670-0.00001-9.

Sohrab Almasi, Kambiz Bahaadinbeigy, Hossein Ahmadi, Solmaz Sohrabei, and Reza Rabiei. Usability evaluation of dashboards: A systematic literature review of tools, 2023. ISSN 23146141.

Richard Brath and Michael Peters. Dashboard design. *DM review*, 2004.

Vania Aparecida Rosario de Oliveira, Geraldo César Rosario de Oliveira, and Valerio Antonio Pamplona Salomon. *Multi-criteria Analysis of Maintenance Management Performance Indicators*. 2023. 10.1007/978-3-031-36121-0_6.

William Ho. Integrated analytic hierarchy process and its applications - a literature review. *European Journal of Operational Research*, 186, 2008. ISSN 03772217. 10.1016/j.ejor.2007.01.004.

Varindya Ditta Iswari, Florentina Yuni Arini, and Much Aziz Muslim. Decision support system for the selection of outstanding students using the ahp-topsis combination method. *Lontar Komputer : Jurnal Ilmiah Teknologi Informasi*, 2019. ISSN 2088-1541. 10.24843/lkjiti.2019.v10.i01.p05.

S Kaganski, J Majak, K Karjust, and S Toompalu. Implementation of key performance indicators selection model as part of the enterprise analysis model. volume 63, pages 283–288, 2017. 10.1016/j.procir.2017.03.143. URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028657784&doi=10.1016%2fj.procir.2017.03.143&partnerID=40&md5=4d96a927fba6d85db44b17b915cbbac5. Cited By :43 Export Date: 2 May 2024.

Ningxuan Kang, Cong Zhao, Jingshan Li, and John A. Horst. A hierarchical structure of key performance indicators for operation management and continuous improvement in production systems. *International Journal of Production Research*, 54, 2016. ISSN 1366588X. 10.1080/00207543.2015.1136082.

Bettina Laugwitz, Theo Held, and Martin Schrepp. Construction and evaluation of a user experience questionnaire. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, volume 5298 LNCS, 2008. 10.1007/978-3-540-89350-9_6.

Shadan Malik. *Enterprise Dashboards Design and Best Practices for IT*, volume 53. 2013.

Ken Peffers, Tuure Tuunanen, Marcus A. Rothenberger, and Samir Chatterjee. A design science research methodology for information systems research. *Journal of Management Information Systems*, 24, 2007. ISSN 07421222. 10.2753/MIS0742-1222240302.

Thomas L. Saaty. How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, 48, 1990. ISSN 03772217. 10.1016/0377-2217(90)90057-I.

Mark N. K. Saunders, Lewis Philip, and Adrian Thornhill. *Research methods for business students*, volume limi. 2019.

Martin Schrepp. User experience questionnaire handbook. *URL: https://www. researchgate. net/publication/303880829*$\{_\}User\{_\}Experience\{_\}Questionnaire\{_\}Handbook\{_\}Version\{_\}2.(Accessed:$

02.02.2017), 2019.

Gayane Sedrakyan, Erik Mannens, and Katrien Verbert. Guiding the choice of learning dashboard visualizations: Linking dashboard design and data visualization concepts. *Journal of Visual Languages and Computing*, 50, 2019. ISSN 25901184. 10.1016/j.jvlc.2018.11.002.

Hsu Shih Shih, Huan Jyh Shyur, and E. Stanley Lee. An extension of topsis for group decision making. *Mathematical and Computer Modelling*, 45, 2007. ISSN 08957177. 10.1016/j.mcm.2006.03.023.

Gwo Hshiung Tzeng and Jih Jeng Huang. *Multiple attribute decision making: Methods and applications*. CRC Press, 1 2011. ISBN 9781439861585.

Arnold van Winden and Hans Heerkens. *Solving managerial problems systematically.* Noordhoff uitgevers, 2016. ISBN 9789001887957.

Martina Varisco, Charlotta Johnsson, Jacob Mejvik, Massimiliano M. Schiraldi, and Li Zhu. Kpis for manufacturing operations management: driving the iso22400 standard towards practical applicability. volume 51, 2018. 10.1016/j.ifacol.2018.08.226.

Dragan Vasiljevic, Zorica Trkulja, and Milos Danilovic. Towards an extended set of production line performance indicators. *Total Quality Management Business Excellence*, 25:618–634, 4 2014. ISSN 14783363. 10.1080/14783363.2013.850811. URL `http://ezproxy2.utwente.nl/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=94419357&site=ehost-live`. Accession Number: 94419357; Vasiljevic, Dragan 1; Trkulja, Zorica 2; Danilovic, Milos 1; Email Address: danilovicm@fon.bg.ac.rs; Affiliations: 1: Department of Operations Management, Faculty of Organizational Sciences, University of Belgrade, Belgrade, Serbia; 2: Grundfos, Indjija, Serbia;; Issue Info: 2014, Vol. 25 Issue 5/6, p618; Thesaurus Term: Assembly line methods; Thesaurus Term: Key performance indicators (Management); Thesaurus Term: Business intelligence; Thesaurus Term: Continuous improvement process; Thesaurus Term: Organizational performance; Thesaurus Term: Economic value added (Corporations); Thesaurus Term: Balanced scorecard; Thesaurus Term: Market value added; Author-Supplied Keyword: business intelligence; Author-Supplied Keyword: continuous improvement support; Author-Supplied Keyword: mixed production and packaging line; Author-Supplied Keyword: performance gap; Author-Supplied Keyword: real-time performance management modeling; NAICS/Industry Codes: 541611 Administrative Management and General Management Consulting Services; Number of Pages: 17p; Document Type: Article; Full Text Word Count: 6542.

Pema Wangdra, Narat Hasachoo, and Pornwasin Sirisawat. Prioritizing key performance indicators for small state-owned airport operation based on topsis: A case study of paro international airport. 2018.

Roel J. Wieringa. *Design science methodology: For information systems and software engineering.* 2014. 10.1007/978-3-662-43839-8.

Shaher H. Zyoud and Daniela Fuchs-Hanusch. A bibliometric-based survey on ahp and topsis techniques, 2017. ISSN 09574174.

Appendices

A Systematic literature review

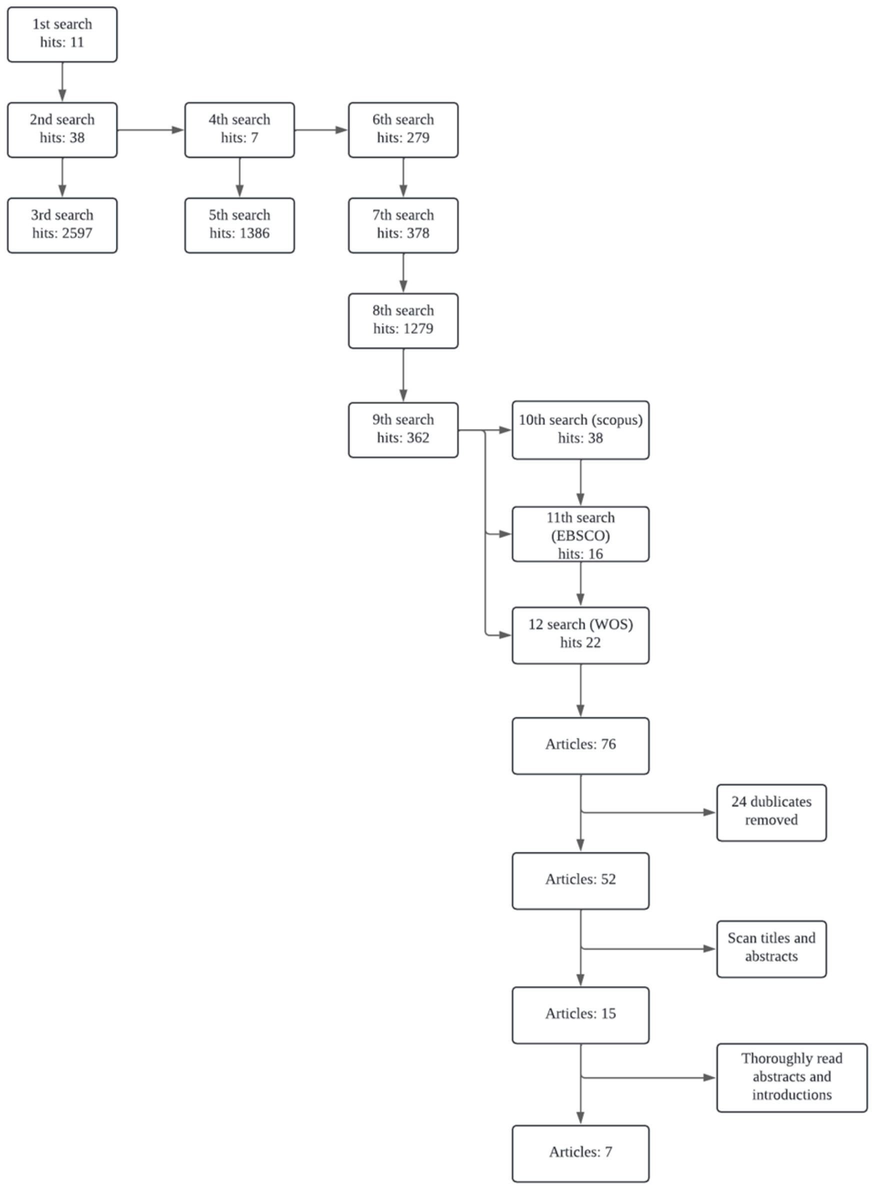


Figure 14: SLR flowchart

Figure 15: Main findings SLR

Articles	Main findings
Ante G et al. (2018)	Selecting the right KPIs is essential for good performance monitoring. Companies should focus on reliability, sustainability, productivity and flexibility.
Varisco M, et al. (2018)	With KPIs a gap between norm and reality (what is and what should be) can be identified. However, finding the right KPIs can be a challenge.
Brundage M, et al. (2017)	There exists a certain dependency between KPIs, they are not all independent.
Kang N, et al. (2017)	Some KPIs are related to each other. The author has created a categorization of the KPIs to give a better overview. The KPIs are from the ISO (international organization of standardization) document.
Kaganski S, et al (2017)	Monitoring KPIs is essential for performance, but selecting the right ones is hard. The EAM (enterprise analysis model) helps identifying bottle necks. This is a survey.
Vasiljevic D, et al. (2014)	Performance management has become more popular. A useful metric is the OEE (overall equipment effectiveness. There are multiple indicators of efficiency. Essential of progress is selecting the right set of KPIs.
Braglia M, et al. (2019)	Lean management is the reduction of waste. An essential KPI for this is the OEE. However, for an engineer to order environment the OTE (overall task effectiveness) is more useful. This KPI focusses more on the single tasks that have to be done (assembly, painting etc.).

B Interview setup

Estimated time
The interview will take around 30 minutes, but no longer than 60 minutes.

Introduction interviewer

- Name interviewer
- Function interviewer (intern Togetr, bacherlor thesis)
- Description of the assignment

Purpose of the interview
The purpose of the interview is to gain insight into the preferences of the company and the clients for the shopfloor dashboard.

Relevance of the interview
The future dashboard is most likely going to be used by the client and the company. Through this interview the interviewees have the chance to share their input and opinions which might be used when developing the dashboard.

Consent and data privacy

- Ask consent to record interview
- Ask how the interviewee wishes to be
- Ask if data from the interview may be used in the report

Interview questions/prompts

- What is your function within the company?
- Will a dashboard of the shopfloor be relevant/useful to you?
- How will you use the dashboard?
- What would you like to see in a shopfloor dashboard?
- What KPIs should be visualized in a dashboard?

C KPIs from literature

Table 16: KPIs according to Kang, et al (2016)

Category	KPI	Abbreviation
Supporting elements: Time	Planned operation time	POT
Supporting elements: Time	Planned busy time	PBT
Supporting elements: Time	Planned down time	PDOT
Supporting elements: Time	Planned run time per item PRI	PRI
Supporting elements: Time	Planned unit set up time	PUST
Supporting elements: Time	Planned order execution time	POET
Supporting elements: Time	Actual unit processing time	AUPT
Supporting elements: Time	Actual production time	APT
Supporting elements: Time	Actual unit setup time	AUST
Supporting elements: Time	Actual unit down time	ADOT
Supporting elements: Time	Actual unit idle time	AUIT
Supporting elements: Time	Actual unit busy time	AUBT
Supporting elements: Time	Actual order execution time	AOET
Supporting elements: Time	Actual transportation time	ATT
Supporting elements: Time	Actual queueing time	AQT
Supporting elements: Time	Actual personnel attendance time	APAT
Supporting elements: Time	Actual personnel work time	APWT
Supporting elements: quantity	Good quantity	GQ
Supporting elements: quantity	Scrap quantity	SQ
Supporting elements: quantity	Planned scrap quantity	PSQ
Supporting elements: quantity	Rework quantity	RQ
Supporting elements: quantity	Processed quantity	PQ
Supporting elements: quantity	Produced quantity in the first operation process	PQF
Supporting elements: maintenance	Time to failure	TTF
Supporting elements: maintenance	Operating time between failures	OTBF
Supporting elements: maintenance	Time to repair	TTR
Supporting elements: maintenance	Failure event	FE
Supporting elements: maintenance	Corrective maintenance time	CMT
Supporting elements: maintenance	Preventive maintenance time	PMT
Basic KPIs: production KPIs	Availabilty	A
Basic KPIs: production KPIs	Allocation efficiency	AE
Basic KPIs: production KPIs	Technical efficiency	TE
Basic KPIs: production KPIs	Worker efficiency	WE
Basic KPIs: production KPIs	Utilization efficiency	UE
Basic KPIs: production KPIs	Effectiveness	E
Basic KPIs: production KPIs	Set up ratio	SeR
Basic KPIs: production KPIs	Allocation ratio	AR
Basic KPIs: production KPIs	Production process ratio	PR
Basic KPIs: production KPIs	Throughput rate	TR
Basic KPIs: production KPIs	Blockage ratio	BL
Basic KPIs: production KPIs	Starvation ratio	ST

Basic KPIs: production KPIs	Work in process	WIP
Supporting elements: time	Blocking time	BLT
Supporting elements: time	Starving time	STT
Supporting elements: time	Buffer capacity	B
Basic KPIs: quality	Actual to planned scrap ratio	SQR
Basic KPIs: quality	Scarp ratio	SR
Basic KPIs: quality	Rework ratio	RR
Basic KPIs: quality	Fall off ratio	FR
Basic KPIs: quality	First time quality	FTQ
Basic KPIs: quality	Quality buy rate	QBR
Basic KPIs: Maintenance	Mean time to failure	MTTF
Basic KPIs: Maintenance	Mean time to repair	MTTR
Basic KPIs: Maintenance	Mean operating time between failures	MOTBF
Basic KPIs: Maintenance	Mean delay time	MDET
Basic KPIs: Maintenance	Meat setup time	MSET
Basic KPIs: Maintenance	Corrective maintenance ratio	CMR
Comprehensive KPIs	Overall equipment effectiveness	OEE
Comprehensive KPIs	Net equipment effectiveness	NEE
Comprehensive KPIs	Line through put rate	LTR

D Cleaned up data

TicketID	Type	Reported At	Solved at	Period	Description	Machine ID	Duration maintenance (min)
M00001	Corrective	09/07/2024 10:30:00	09/07/2024 12:45:00	31/12/1899 02:15:00	Verstoring aan machines	Machine A	135
M00002	Preventive	09/07/2024 05:00:00	09/07/2024 06:00:00	31/12/1899 01:00:00	Gepland onderhoud	Machine A	60
M00003	Preventive	12/08/2024 12:30:00	12/08/2024 14:45:00	31/12/1899 02:15:00	Gepland onderhoud	Machine B	135
M00004	Corrective	29/08/2024 11:15:00	29/08/2024 16:15:00	31/12/1899 05:00:00	Verstoring aan machines	Machine B	300
M00005	Corrective	11/09/2024 10:00:00	11/09/2024 10:30:00	31/12/1899 00:30:00	Verstoring aan machines	Machine A	30
M00006	Preventive	10/10/2024 16:00:00	10/10/2024 18:00:00	31/12/1899 02:00:00	Gepland onderhoud	Machine B	120
M00007	Corrective	04/11/2024 10:30:00	04/11/2024 13:30:00	31/12/1899 03:00:00	Verstoring aan machines	Machine B	180
M00008	Corrective	30/11/2024 14:30:00	30/11/2024 16:00:00	31/12/1899 01:30:00	Verstoring aan machines	Machine A	90

Figure 16: Data: Maintenance

Ordernumber	Position	Task	Department	Occupants	Machines occupied	Input	Ready	Scrap quantity	Remaining
PO-2401-1009	10	Assembly - standard	Assembly (standard)	1	0	50	50	0	0
PO-2401-1009	20	Quality check	Quality check	1	0	50	49	1	0
PO-2401-1010	10	Assembly - standard	Assembly (standard)	1	0	30	28	2	0
PO-2401-1010	20	Quality check	Quality check	1	0	28	28	0	0
PO-2401-1011	10	Assembly - standard	Assembly (standard)	1	0	25	22	3	0
PO-2401-1011	20	Quality check	Quality check	1	0	22	22	0	0
PO-2401-1012	10	Assembly - standard	Assembly (standard)	1	0	27	26	1	0
PO-2401-1012	20	Quality check	Quality check	1	0	26	25	1	0
PO-2401-1013	10	Assembly - standard	Assembly (standard)	1	0	35	35	0	0
PO-2401-1013	20	Quality check	Quality check	1	0	35	35	0	0

Figure 17: Data: 'production orders operation' part 1

Status	Next task	Planned time	Remaining time	Actual spend time	Waiting time	Set up time	Cycle time	Time between tasks
Ready	20	2315	0	6095	60	15	100	20
Ready		345	0	612	60	0	15	2
Ready	20	2315	0	2783	60	15	100	8
Ready		345	0	636	60	0	15	16
Ready	20	2315	0	2952	60	15	100	2
Ready		345	0	435	60	0	15	1
Ready	20	2135	0	2775	60	15	100	0
Ready		345	0	476	60	0	15	0
Ready	20	2135	0	3587	60	15	100	12
Ready		345	0	588	60	0	15	3

Figure 18: Data: 'production orders operation' part 2

Planned time in days	Earliest start date	Start production	Production completed	Actual spend time in days	Actual cycle time	Earliest completed
11	31/01/2024	31/01/2024	12/02/2024	13	120	10/02/2024
2	10/02/2024	12/02/2024	13/02/2024	2	11	12/02/2024
7	10/02/2024	12/02/2024	17/02/2024	6	90	16/02/2024
1	16/02/2024	17/02/2024	19/02/2024	2	20	17/02/2024
6	16/02/2024	17/02/2024	23/02/2024	7	115	21/02/2024
1	21/02/2024	23/02/2024	24/02/2024	1	17	22/02/2024
6	21/02/2024	23/02/2024	28/02/2024	6	100	26/02/2024
1	26/02/2024	28/02/2024	29/02/2024	1	16	27/02/2024
8	26/02/2024	28/02/2024	06/03/2024	8	100	04/03/2024
2	04/03/2024	06/03/2024	07/03/2024	2	15	05/03/2024

Figure 19: Data: 'production orders operation' part 3

Ordernumber	Origin	Status	Start date	Delivery date	Requested delivery date	Date completed	Warehouse	Item	Amount
PO-2401-1009	Supply Chain	Ready / Close order	Wednesday, 31 January 2024	13/02/2024	12/02/2024	13/02/2024	VDL	ABBI_95302-WS	50
PO-2401-1010	Supply Chain	Ready / Close order	Monday, 12 February 2024	19/02/2024	17/02/2024	19/02/2024	VDL	ABBI_95302-WS	30
PO-2401-1011	Supply Chain	Ready / Close order	Saturday, 17 February 2024	24/02/2024	22/02/2024	24/02/2024	VDL	ABBI_95302-WS	25
PO-2401-1012	Supply Chain	Ready / Close order	Friday, 23 February 2024	29/02/2024	27/02/2024	29/02/2024	VDL	ABBI_95302-WS	27
PO-2401-1013	Supply Chain	Ready / Close order	Wednesday, 28 February 2024	07/03/2024	05/03/2024	07/03/2024	VDL	ABBI_95302-WS	35

Figure 20: Data: 'production orders'

E Formulas top ranked KPIs

Table 17: Final KPIs with formulas

KPI	**Formula**
Overall equipment effectiveness	OEE = A * E * QBR A =(APT/PBT)*100% E = ((PRI * PQ)/APT)* 100%
Quality buy rate	QBR = ((GQ + RQ)/PQ) * 100% PQ = PQF + RQ PQF = GQ + SQ + RQ
Net equipment effectiveness	NEE = (AUPT/PBT) * E * QBR AUPT = APT + AUST
Planned scrap quantity	No data
Scrap ratio	SR = (SQ/PQ)* 100% PQ = PQF + RQ
Scrap quantity	
Actual to planned scrap ratio	SQR = (SQ/PSQ) * 100%
First time quality	FTQ = (GQ/PQF) * 100% PQF = GQ + SQ + RQ
Average hour distribution operations	(operation time)/(sum operation time) * 100%
Average hour distribution per product	deel/geheel * 100%
Throughput rate	TR = ((GQ+RQ)/AOET) * 100% AOET= AUBT + ATT + AQT + ADET
Amount of returns	No data
Good quantity	
Fall off ratio	FR = 1 - (PQF/PQ) * 100% PQF = GQ + SQ + RQ PQ = PQF + RQ
Rework quantity	No data
Rework ratio	RR = (RQ/PQ)*100%
Actual unit down time	
Corrective maintenance ratio	CMR = (CMT/PMT) * 100%
Mean delay time	No data
Mean time to repair	
Time to repair	
Preventive maintenance time	
Planned scrap quantity	ST = (STT/PBT) * 100%

Amount of returns	No data
Failure event	
Line throughput rate	

F Research design

Table 18: Research design

Research design	**Type of research**	**Population**	**Subjects**	**Research strategy**	**Data gathering method**	**Data processing method**	**Action plan**
How does the shopfloor module process look like in the software?	Descriptive	Implementation team	Employees	Deep qualitative	Interview with observation of simulation on test software (cross-sectional)	Visual representation of software (screenshots, flowchart), description	Interview employees, observe test software, make flow chart
What has Togetr already done to visualize data in the shopfloor module?	Exploratory	Implementation team and development	Employees	Deep qualitative	Interview (cross – sectional)	Description, qualitative	Interview employees, write a description
What KPIs do the clients of Togetr want to see in a dashboard?	Descriptive	Clients of Togetr, operators	Clients	Deep qualitative	Interview (cross – sectional)	List of KPIs, qualitative	Interview clients, create list of KPIs
What KPIs does Togetr want to see in a dashboard?	Descriptive	Implementation team and development	Employees	Deep qualitative	Interview (cross – sectional)	List of KPIs, qualitative	Interview employees, create list of KPIs
What KPIs are related to shopfloor operations according to literature?	Descriptive	Literature	Database, researchers	Deep qualitative	Systematic literature review (cross – sectional)	List of KPIs, qualitative	Literature study, make list of KPIs
What is the best way to choose a set of KPIs?	Descriptive	Literature	Database, researchers, selection tool	Broad qualitative	Literature study (cross – sectional)	Descriptive list of selection methods, qualitative	Literature study, different method, choose best method
What data is needed to calculate the KPIs?	Descriptive	Literature	Database, datasets	Deep qualitative	Literature study (cross – sectional)	List of data that is needed, qualitative	Literature study, data needed for calculation, organize in a list
What data models does Togetr have available?	Descriptive	Development team	Employees, datasets	Deep qualitative	Interview (cross – sectional)	List of available data, qualitative	Interview employees, create list of available data
Which visuals fits each chosen KPI the best?	Descriptive	Literature	Database, chosen KPIs	Broad qualitative	Literature study (cross – sectional)	Description of options, table, qualitative	Literature study, table with options, description options
What is the best way to present the dashboard to Togetr?	Descriptive	Literature	Dashboard, employees	Broad qualitative	Literature study (cross – sectional)	Description of options, qualitative	Literature study, description of different options
What is the best way to present the dashboard to the clients?	Descriptive	Literature	Dashboard, clients	Broad qualitative	Literature study (cross – sectional)	Description of options, qualitative	Literature study, description of different options
What are criteria of a 'good' dashboard?	Decsriptive	Literature	Database, researchers' dashboard	Broad qulaitative	Literature study (cross – sectional)	List of requirements, qualitative	Literature study, list of requirements
What are neutral questions to evaluate a dashboard?	Decsriptive	Literature	Database, researchers' dashboard	Broad qualitative	Literature study (cross – sectional)	List of questions for survey, qualitative	Literature study, list of questions

G Unfiltered list of KPIs

Table 19: Combined list of KPIs (interviews and literature)

KPI/metric	Abbriviation
Planned operation time	POT
Planned busy time	PBT
Planned down time	PDOT
Planned run time per item PRI	PRI
Planned unit set up time	PUST
Planned order execution time	POET
Actual unit processing time	AUPT
Actual production time	APT
Actual unit setup time	AUST
Actual unit down time	ADOT
Actual unit idle time	AUIT
Actual unit busy time	AUBT
Actual order execution time	AOET
Actual transportation time	ATT
Actual queueing time	AQT
Actual personnel attendance time	APAT
Actual personnel work time	APWT
Good quantity	GQ
Scrap quantity	SQ
Planned scrap quantity	PSQ
Rework quantity	RQ
Processed quantity	PQ
Produced quantity in the first operation process	PQF
Time to failure	TTF
Operating time between failures	OTBF
Time to repair	TTR
Failure event	FE
Corrective maintenance time	CMT
Preventive maintenance time	PMT
Availabilty	A
Allocation efficiency	AE
Technical efficiency	TE
Worker efficiency	WE
Utilization efficiency	UE
Effectiveness	E
Set up ratio	SeR
Allocation ratio	AR
Production process ratio	PR
Throughput rate	TR
Blockage ratio	BL
Starvation ratio	ST

Table 19: Combined list of KPIs (interviews and literature)

KPI/metric	**Abbriviation**
Work in process	WIP
Blocking time	BLT
Starving time	STT
Buffer capacity	B
Actual to planned scrap ratio	SQR
Scarp ratio	SR
Rework ratio	RR
Fall off ratio	FR
First time quality	FTQ
Quality buy rate	QBR
Mean time to failure	MTTF
Mean time to repair	MTTR
Mean operating time between failures	MOTBF
Mean delay time	MDET
Meat setup time	MSET
Corrective maintenance ratio	CMR
Overall equipment effectiveness	OEE
Net equipment effectiveness	NEE
Line through put rate	LTR
Average issues in software	AIS
Throughput time	TPT
Amount of returns	AR
Invoice tardiness	IT
Actual credit use	ACU
Capacity	C
Average reminders for invoice	ARC
Reliability operation planning	ROP
Job satisfaction	JS
Average hour distribution operations	AHDO
Average hour distribution per product	AHDP
Reliability planning	RP
Overall equipment effectiveness	OEE
Reliability planning	RP
Inventory value	IV
Revenue per year	R
Order intake per month	OIM
Ratio cost an inventory value	RCIV
Idle time machine	ITM
Availability	A
Average hour distribution operations	AHDO
Average hour distribution per product	AHDP
Inventory stock	IS
Avergage working hours per machine	AUBT

Table 19: Combined list of KPIs (interviews and literature)

KPI/metric	Abbriviation
Scrap quantity	SQ

H Selecting the KPIs

Table 20: Normalized table

KPI/criteria	Cost	Time	Maintenance	Quality
AOET	0,0724	0,1385	0,0933	0,0830
APAT	0,1447	0,1385	0,0466	0,0830
APWT	0,1447	0,1385	0,0466	0,0830
APT	0,0724	0,1385	0,0933	0,0830
AQT	0,0724	0,1385	0,0933	0,0415
SQR	0,1447	0,0277	0,0933	0,2074
ATT	0,0724	0,1385	0,0933	0,0415
AUBT	0,0724	0,1385	0,0933	0,0830
ADOT	0,1447	0,1108	0,2331	0,1245
AUIT	0,0724	0,1385	0,0466	0,0415
AUPT	0,0724	0,1385	0,0933	0,0415
AUST	0,0724	0,1385	0,0933	0,0415
AE	0,0724	0,1385	0,0933	0,1245
AR	0,0724	0,1385	0,0933	0,1245
AOR	0,1447	0,0554	0,1399	0,1659
A	0,1447	0,1108	0,0933	0,0830
AHDO	0,0724	0,1385	0,0466	0,0415
AHDP	0,0724	0,1385	0,0466	0,0415
BL	0,0724	0,1385	0,1399	0,0830
BLT	0,0724	0,1385	0,1399	0,0830
B	0,0724	0,0277	0,0466	0,0830
C	0,0724	0,0831	0,0933	0,1245
CMR	0,1447	0,1108	0,2331	0,1245
CMT	0,0724	0,1108	0,2331	0,0830
E	0,0724	0,1385	0,0466	0,0830
FE	0,1447	0,0831	0,2331	0,1245
FR	0,1447	0,0554	0,0933	0,1659
FTQ	0,0724	0,0277	0,0933	0,2074
GQ	0,0724	0,0277	0,0466	0,2074
IS	0,1447	0,0277	0,0466	0,0830
IV	0,2894	0,0831	0,0466	0,0415
LTR	0,0724	0,1385	0,1399	0,1245
MDET	0,0724	0,1385	0,1865	0,1245
MOTBF	0,0724	0,1385	0,1399	0,0830
MTTF	0,0724	0,1385	0,0933	0,0830

Table 20: Normalized table

KPI/criteria	Cost	Time	Maintenance	Quality
MTTR	0,0724	0,1385	0,1865	0,1245
MSET	0,0724	0,1385	0,0933	0,0830
NEE	0,0724	0,1385	0,1399	0,1659
OTBF	0,0724	0,1385	0,1399	0,1245
OIM	0,2894	0,0831	0,0466	0,0415
OEE	0,0724	0,1385	0,2331	0,2074
PBT	0,0724	0,1385	0,0933	0,0830
PDOT	0,0724	0,1385	0,1399	0,0830
POT	0,0724	0,1385	0,0933	0,0830
POET	0,0724	0,1385	0,0933	0,0830
PRI	0,0724	0,1385	0,0466	0,0415
PSQ	0,0724	0,0554	0,0933	0,2074
PUST	0,1447	0,1108	0,0466	0,0415
PMT	0,0724	0,1108	0,2331	0,1245
PQ	0,0724	0,0554	0,0933	0,1245
PQF	0,0724	0,0554	0,0933	0,1245
PR	0,0724	0,1385	0,1399	0,1245
QBR	0,1447	0,0554	0,0933	0,2074
RCIV	0,3618	0,0277	0,0466	0,0830
ROP	0,0724	0,1385	0,0933	0,0830
RP	0,1447	0,1385	0,0933	0,0830
RQ	0,0724	0,0554	0,0933	0,1659
RR	0,0724	0,0554	0,0933	0,1659
SR	0,0724	0,0554	0,0933	0,2074
SQ	0,0724	0,0554	0,0933	0,2074
SeR	0,1447	0,1385	0,0933	0,0830
ST	0,1447	0,1385	0,1399	0,1245
STT	0,1447	0,1385	0,1399	0,1245
TE	0,0724	0,1385	0,1399	0,1245
TR	0,0724	0,1385	0,0466	0,1659
TPT	0,0724	0,1385	0,0466	0,0830
TTF	0,0724	0,1385	0,0933	0,0830
TTR	0,0724	0,1385	0,1865	0,1245
UE	0,0724	0,1385	0,1399	0,0830
WIP	0,2894	0,1385	0,0933	0,0830
WE	0,1447	0,1385	0,0466	0,0830

Table 21: Normalized weighted table

KPI/criteria	Cost	Time	Maintenance	Quality
AOET	0,0058	0,0408	0,0149	0,0386
APAT	0,0115	0,0408	0,0075	0,0386

Table 21: Normalized weighted table

KPI/criteria	Cost	Time	Maintenance	Quality
APWT	0,0115	0,0408	0,0075	0,0386
APT	0,0058	0,0408	0,0149	0,0386
AQT	0,0058	0,0408	0,0149	0,0193
SQR	0,0115	0,0082	0,0149	0,0966
ATT	0,0058	0,0408	0,0149	0,0193
AUBT	0,0058	0,0408	0,0149	0,0386
ADOT	0,0115	0,0326	0,0374	0,0580
AUIT	0,0058	0,0408	0,0075	0,0193
AUPT	0,0058	0,0408	0,0149	0,0193
AUST	0,0058	0,0408	0,0149	0,0193
AE	0,0058	0,0408	0,0149	0,0580
AR	0,0058	0,0408	0,0149	0,0580
AOR	0,0115	0,0163	0,0224	0,0773
A	0,0115	0,0326	0,0149	0,0386
AHDO	0,0058	0,0408	0,0075	0,0193
AHDP	0,0058	0,0408	0,0075	0,0193
BL	0,0058	0,0408	0,0224	0,0386
BLT	0,0058	0,0408	0,0224	0,0386
B	0,0058	0,0082	0,0075	0,0386
C	0,0058	0,0245	0,0149	0,0580
CMR	0,0115	0,0326	0,0374	0,0580
CMT	0,0058	0,0326	0,0374	0,0386
E	0,0058	0,0408	0,0075	0,0386
FE	0,0115	0,0245	0,0374	0,0580
FR	0,0115	0,0163	0,0149	0,0773
FTQ	0,0058	0,0082	0,0149	0,0966
GQ	0,0058	0,0082	0,0075	0,0966
IS	0,0115	0,0082	0,0075	0,0386
IV	0,0230	0,0245	0,0075	0,0193
LTR	0,0058	0,0408	0,0224	0,0580
MDET	0,0058	0,0408	0,0299	0,0580
MOTBF	0,0058	0,0408	0,0224	0,0386
MTTF	0,0058	0,0408	0,0149	0,0386
MTTR	0,0058	0,0408	0,0299	0,0580
MSET	0,0058	0,0408	0,0149	0,0386
NEE	0,0058	0,0408	0,0224	0,0773
OTBF	0,0058	0,0408	0,0224	0,0580
OIM	0,0230	0,0245	0,0075	0,0193
OEE	0,0058	0,0408	0,0374	0,0966
PBT	0,0058	0,0408	0,0149	0,0386
PDOT	0,0058	0,0408	0,0224	0,0386
POT	0,0058	0,0408	0,0149	0,0386
POET	0,0058	0,0408	0,0149	0,0386

Table 21: Normalized weighted table

KPI/criteria	Cost	Time	Maintenance	Quality
PRI	0,0058	0,0408	0,0075	0,0193
PSQ	0,0058	0,0163	0,0149	0,0966
PUST	0,0115	0,0326	0,0075	0,0193
PMT	0,0058	0,0326	0,0374	0,0580
PQ	0,0058	0,0163	0,0149	0,0580
PQF	0,0058	0,0163	0,0149	0,0580
PR	0,0058	0,0408	0,0224	0,0580
QBR	0,0115	0,0163	0,0149	0,0966
RCIV	0,0288	0,0082	0,0075	0,0386
ROP	0,0058	0,0408	0,0149	0,0386
RP	0,0115	0,0408	0,0149	0,0386
RQ	0,0058	0,0163	0,0149	0,0773
RR	0,0058	0,0163	0,0149	0,0773
SR	0,0058	0,0163	0,0149	0,0966
SQ	0,0058	0,0163	0,0149	0,0966
SeR	0,0115	0,0408	0,0149	0,0386
ST	0,0115	0,0408	0,0224	0,0580
STT	0,0115	0,0408	0,0224	0,0580
TE	0,0058	0,0408	0,0224	0,0580
TR	0,0058	0,0408	0,0075	0,0773
TPT	0,0058	0,0408	0,0075	0,0386
TTF	0,0058	0,0408	0,0149	0,0386
TTR	0,0058	0,0408	0,0299	0,0580
UE	0,0058	0,0408	0,0224	0,0386
WIP	0,0230	0,0408	0,0149	0,0386
WE	0,0115	0,0408	0,0075	0,0386

Table 22: Ideal best and ideal worst

	Cost	Time	Maintenance	Quality
V+	0,0288	0,0408	0,0374	0,0966
V-	0,0058	0,0082	0,0075	0,0193

Table 23: Distances and performance score

KPI/criteria	SI+	SI-	PI
AOET	0,0663	0,0386	0,3683
APAT	0,0675	0,0384	0,3624
APWT	0,0675	0,0384	0,3624
APT	0,0663	0,0386	0,3683
AQT	0,0837	0,0335	0,2856
SQR	0,0432	0,0779	0,6433

Table 23: Distances and performance score

KPI/criteria	SI+	SI-	PI
ATT	0,0837	0,0335	0,2856
AUBT	0,0663	0,0386	0,3683
ADOT	0,0431	0,0549	0,5604
AUIT	0,0860	0,0326	0,2750
AUPT	0,0837	0,0335	0,2856
AUST	0,0837	0,0335	0,2856
AE	0,0503	0,0511	0,5043
AR	0,0503	0,0511	0,5043
AOR	0,0386	0,0607	0,6110
A	0,0650	0,0326	0,3338
AHDO	0,0860	0,0326	0,2750
AHDP	0,0860	0,0326	0,2750
BL	0,0641	0,0408	0,3885
BLT	0,0641	0,0408	0,3885
B	0,0765	0,0193	0,2017
C	0,0528	0,0426	0,4464
CMR	0,0431	0,0549	0,5604
CMT	0,0629	0,0432	0,4071
E	0,0692	0,0379	0,3541
FE	0,0454	0,0518	0,5333
FR	0,0421	0,0593	0,5848
FTQ	0,0458	0,0777	0,6291
GQ	0,0499	0,0773	0,6078
IS	0,0749	0,0202	0,2120
IV	0,0847	0,0237	0,2190
LTR	0,0474	0,0527	0,5267
MDET	0,0456	0,0553	0,5482
MOTBF	0,0641	0,0408	0,3885
MTTF	0,0663	0,0386	0,3683
MTTR	0,0456	0,0553	0,5482
MSET	0,0663	0,0386	0,3683
NEE	0,0336	0,0682	0,6701
OTBF	0,0474	0,0527	0,5267
OIM	0,0847	0,0237	0,2190
OEE	0,0230	0,0891	0,7947
PBT	0,0663	0,0386	0,3683
PDOT	0,0641	0,0408	0,3885
POT	0,0663	0,0386	0,3683
POET	0,0663	0,0386	0,3683
PRI	0,0860	0,0326	0,2750
PSQ	0,0404	0,0781	0,6591
PUST	0,0850	0,0251	0,2281
PMT	0,0457	0,0546	0,5445

Table 23: Distances and performance score

KPI/criteria	SI+	SI-	PI
PQ	0,0559	0,0402	0,4183
PQF	0,0559	0,0402	0,4183
PR	0,0474	0,0527	0,5267
QBR	0,0374	0,0783	0,6767
RCIV	0,0729	0,0300	0,2918
ROP	0,0663	0,0386	0,3683
RP	0,0645	0,0391	0,3772
RQ	0,0448	0,0590	0,5687
RR	0,0448	0,0590	0,5687
SR	0,0404	0,0781	0,6591
SQ	0,0404	0,0781	0,6591
SeR	0,0645	0,0391	0,3772
ST	0,0449	0,0531	0,5417
STT	0,0449	0,0531	0,5417
TE	0,0474	0,0527	0,5267
TR	0,0424	0,0665	0,6108
TPT	0,0692	0,0379	0,3541
TTF	0,0663	0,0386	0,3683
TTR	0,0456	0,0553	0,5482
UE	0,0641	0,0408	0,3885
WIP	0,0624	0,0423	0,4041
WE	0,0675	0,0384	0,3624

I First draft of dashboard

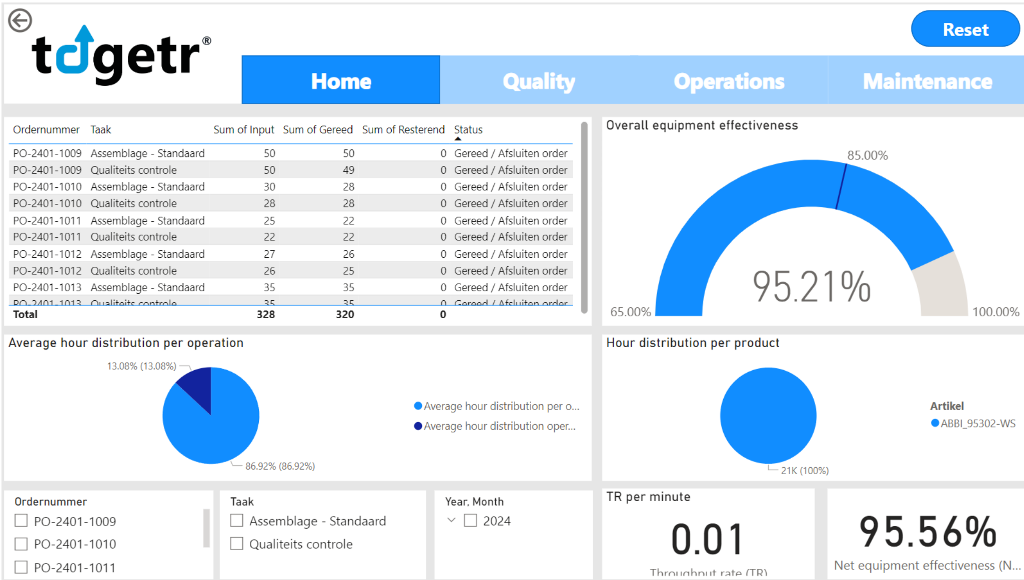


Figure 21: Home

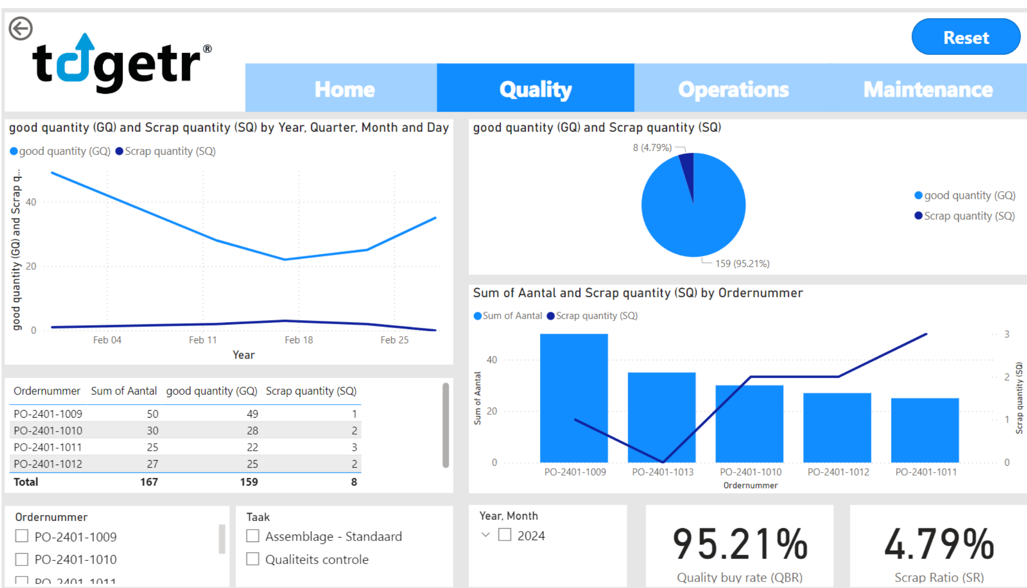


Figure 22: Quality

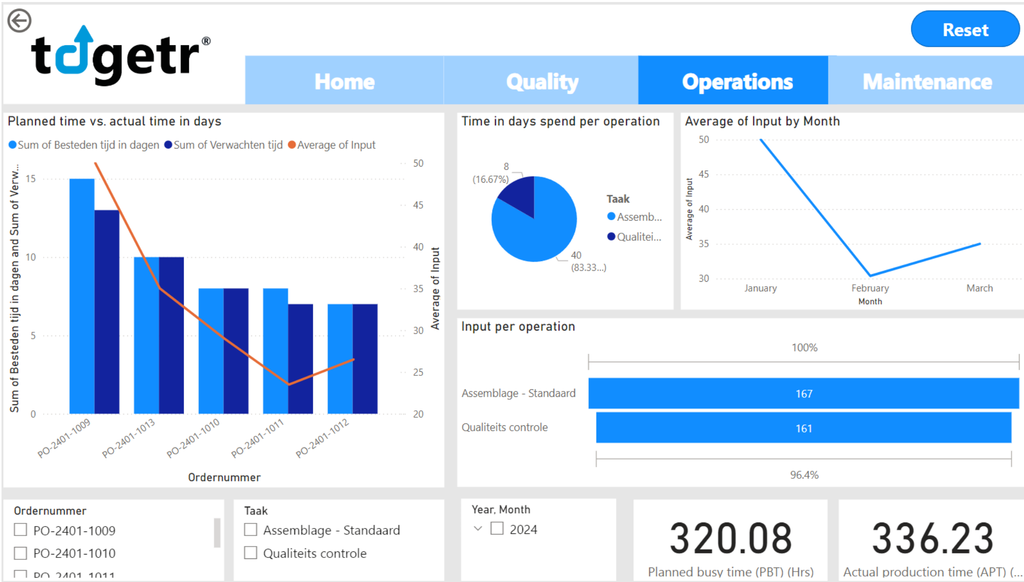


Figure 23: Operations

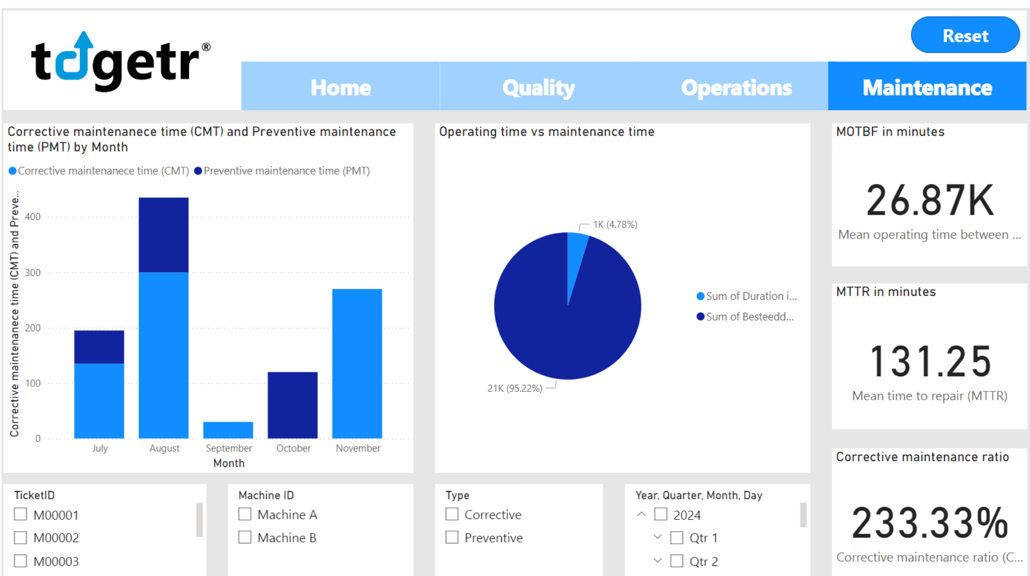


Figure 24: Maintenance

J Final draft of dashboard

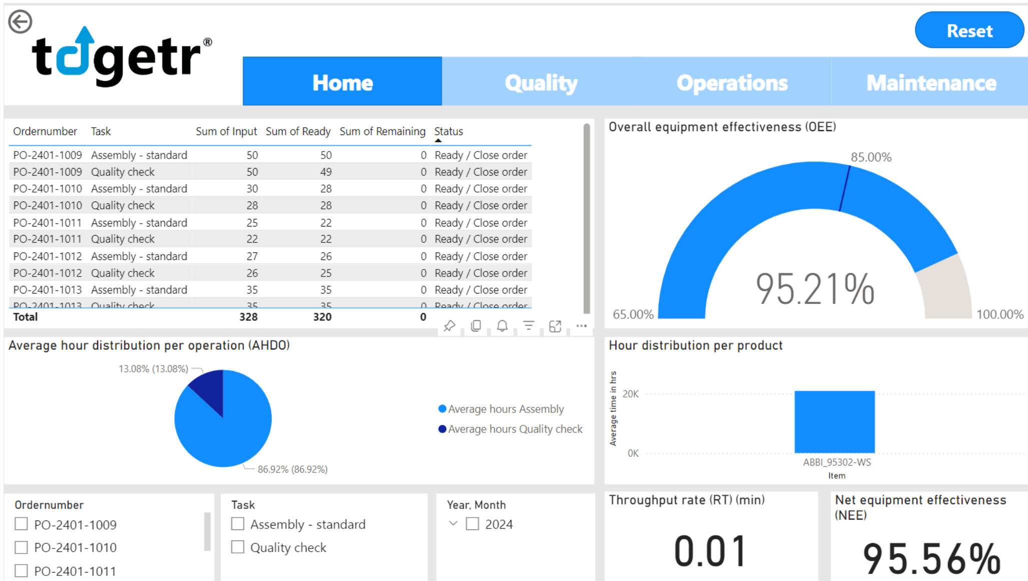


Figure 25: Home

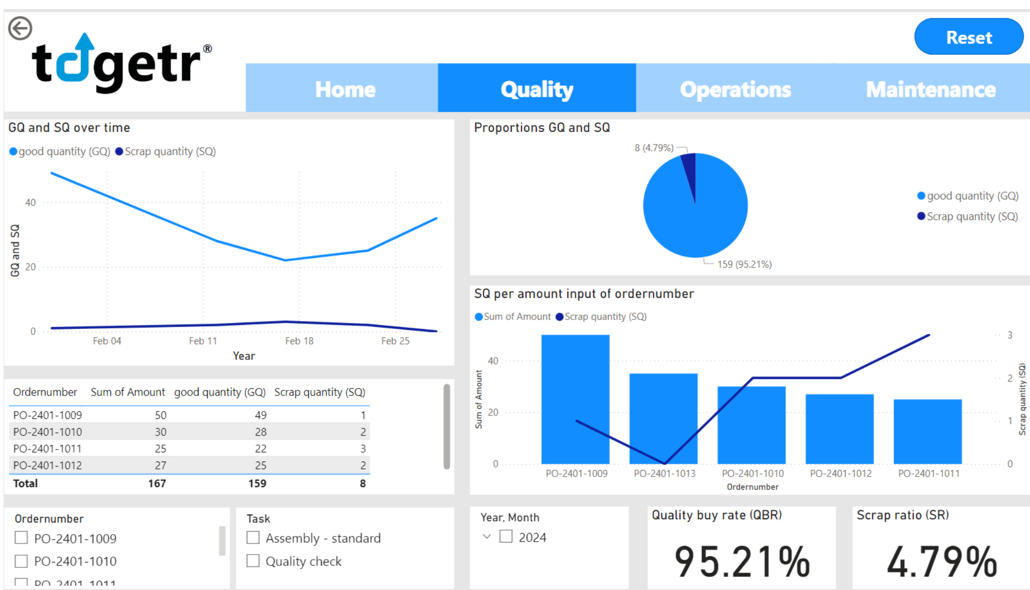


Figure 26: Quality

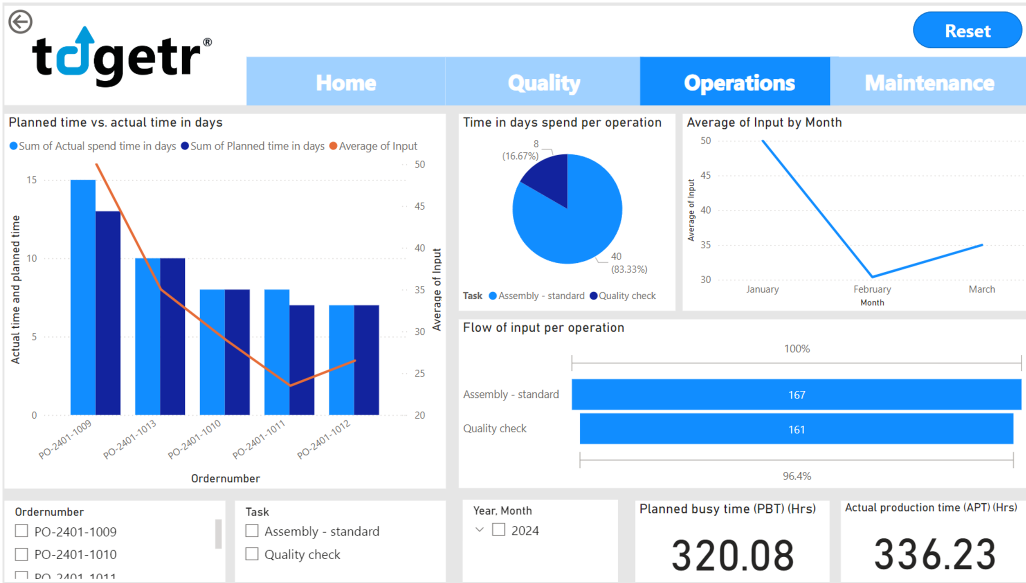


Figure 27: Operations

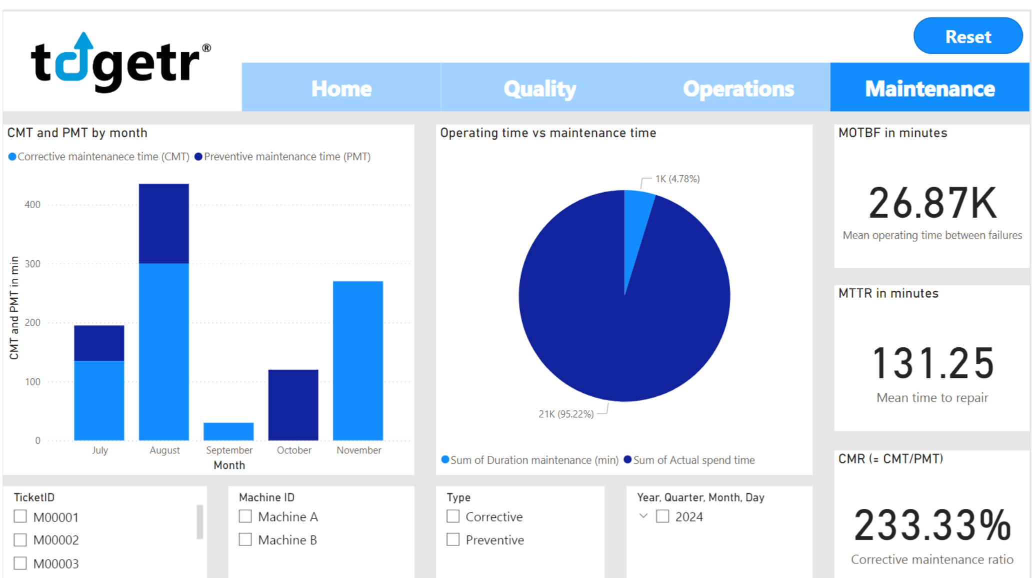


Figure 28: Maintenance