DESIGNING A KPI DASHBOARD FOR THE TEST PROCESS OF TAPE DRIVES AT BLUETRON

Bachelor Thesis

I.de Kruif (Iris)

University of Twente

Faculty of Behavioral, Management, and Social Sciences

Bachelor of Science in Industrial Engineering and Management

September 2023

BSc Industrial Engineering & Management

Designing a KPI dashboard for the test process of tape drives at Bluetron

Author: I. de Kruif (Iris)

s2544490

This thesis was written as part of the Bachelor thesis project assignment in the Industrial Engineering & Management educational program

UNIVERSITY OF TWENTE.

University of Twente
Drienerlolaan 5
7522 NB Enschede

Bluetron B.V.
Traverse 1
3905 NL Veenendaal

Supervisors
1st : Dr. G. Sedrakyan (Gayane)
2nd : Dr. L.O. Meertens (Lucas)

Supervisor
F. van de Vliert (Ferry)

Management Summary

Introduction

Bluetron, a rapidly growing company specializing in Electronics, Infra, and Data life-cycle services, initiated this research due to an increase in throughput time for tape drive testing. The primary cause of this delay is the absence of insights into the bottlenecks of the tape drive test process. The company's goal with this research is to achieve insights into these bottlenecks. We have defined three objectives to measure our success: (1) the effectiveness and (2) the efficiency of employees gaining insights into bottlenecks, and (3) the ability of the dashboard prototype to support locating bottlenecks in the tape drive testing process. To address this challenge, we've determined that a dashboard is the most suitable tool and formulated the research question: *'How can the bottlenecks in the tape drive test process be detected using a KPI dashboard?'*

Findings

Findings of this research include (1) a list of KPIs relevant for tracking bottlenecks determined through a literature review, interviews, and the Analytic Hierarchy Process, (2) recommendations for dashboard design approaches by looking into visual analytics principles and combining with behavior change theories to support the acceptance, (3) a prototype solution that allowed to test the KPI dashboard. The evaluation showed that the prototype of the dashboard increased the score for effectiveness in terms of data generation with 0.25 on the 5-point Likert scale. Moreover, the score for effectiveness in terms of data interpretability increased with 2 on the Likert scale, and the score for effectiveness in terms of information completeness of bottlenecks increased with 2.5 on the Likert scale. The score of the second objective, efficiency in terms of time, increased with 2 on the Likert scale after the introduction of the prototype. The third objective, the ability of the dashboard prototype to locate bottlenecks, is measured through an attempt to locate and eliminate a bottleneck in the tape drive test process. We found that the prototype has shown the ability to locate bottlenecks in the tape drive test process during the evaluation process.

Conclusions

The research findings show that the perception of employees about data generation, data interpretability, information completeness, and efficiency in terms of time has improved by the introduction of the prototype solution. Moreover, the dashboard prototype has shown the ability to locate bottlenecks in the tape drive test process. We can state that the prototype improved the three objectives we set and decreased the discrepancy between norm and reality. We conclude that the prototype solution we introduced is capable of communicating inishgts into the bottlenecks of the test process of tape drives at Bluetron. We do, however, have to note that the prototype has only been tested and not implemented at Bluetron. The real success of the prototype can in reality differ from this conclusion and may in addition need further adaptations and enhancements based on the (re-)evaluation loops and future needs of the company.

Recommendations

- Use the Key Performance Indicators (KPIs) determined in this research for the dashboard, while considering the dynamic nature of the organization, and employ the Design Science Research Methodology for continuous evaluation of the relevance of the KPIs and add or remove KPIs per future needs.
- Visualize selected KPIs following the guidelines established in this research for selecting and evaluating the KPI visualizations.
- Design the dashboard to provide high level perspective to bottlenecks, further enhanced with interactive visualizations to enable zooming into lower level detail as needed.
- Implement changes following Kotter's 8-step change model to ensure employee acceptability, while acknowledging the organization's current restructuring phase.

Preface

Dear reader,

First of all, thank you for reading this thesis. This thesis is the final part of my bachelor Industrial Engineering and Management at the University of Twente. The research is conducted on behalf of Bluetron, a company specializing in life-cycle services. I have been working on this thesis since February 2023 and it was a new experience for me to work on such a big project on my own. It has been a very challenging time in which I learned a lot of new skills, personally and academically. I want to take this opportunity to thank everyone who has in any way helped me finish this thesis successfully.

First, I want to thank Bluetron for giving me the chance to do research inside their company. It was a great pleasure to get to know all the employees who have helped me a lot during the past months. I want to specifically thank my company supervisor who provided feedback and guidance when I needed it. Secondly, I want to thank Gayane Sedrakyan, my 1st supervisor, and Lucas Meertens, my 2nd supervisor. Their support and feedback was of great value to me and I could not have done it without their help. Lastly, I want to thank my friends and family who have stood by me during this research period and who offered a helping hand when needed.

Enjoy reading!

Kind regards,

Iris de Kruif

November 2023

Table of Contents

Table of Figures

Table of Tables

List of abbreviations

Abbreviation	Expansion
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BI	Business Intelligence
BPMN	Business Process Modeling Notation
BWM	Best Worst Method
CEO	Chief Executive Officer
DEMATEL	Decision-Making Trail and Evaluation Laboratory
DOA	Dead On Arrival
DSRM	Design Science Research Methodology
ELECTRE	Elimination Et Choix Traduisant la REalite
ERP	Enterprise Resource Planning
GOO	Good
ISM	Interpretive Structural Modeling
KPI	Key Performance Indicator
NDF	No Defect Found
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
RMA	Return Merchandise Authorization
SMART	Specific, Measurable, Attainable, Realistic, Timely
SME	Small and Medium Enterprise
WIP	Work-In-Progress

1 Introduction

This introductory chapter aims to provide information about the problem that the intended stakeholder of this project faces and to formulate a systematic approach to solve this problem. The chapter will first state the context of this research in Section 1.1 and will identify and explain the problem in Section 1.2. Next, the research method will be explained in Section 1.3 in terms of the problem-solving approach, the scope, and the intended deliverables. Thereafter, the research question and the related sub questions will be introduced in Section 1.4. Section 1.5 will explain the research design, together with the activity plans for this research. Lastly, in Section 1.6 of this chapter the theoretical perspective on which this research is built is discussed.

1.1 Company Description

Bluetron is a fast-growing company specializing in life-cycle services in three digital domains: Electronics, Infra, and Data. The Electronics domain deals with (re)design, vendor and parts management, assembly, repair, refurbishment, remanufacturing, up to and including reuse and recycling of all sorts of electronics. The Infra domain handles the design, assembly, repair, and expansion of data center hardware to guarantee the availability of systems and their data. Lastly, the data domain of Bluetron offers 100% Data Guarantee services, which means that a company has the certainty that it will quickly be back in business after a ransomware attack.

The focus of this research is on the Electronics domain, and in particular on the process of testing tape drives. Tape drives are data storage devices that store data on magnetic tape. Tape drives have capacities of up to 45 Terabytes and are mostly used at large companies for backup and archiving purposes. Bluetron receives weekly shipments of defective tape drives from Customer X. The repair engineers test the drives to check whether they are defective or not. The defective drives are outsourced to Partner Y to be repaired and the non-defective drives are sent back to Customer X. Partner Y repairs the drives and sends them back to Bluetron, after which Bluetron sends them repaired back to Customer X again.

1.2 Problem Identification

1.2.1 Motivation for Research

As mentioned before, Bluetron is a fast-growing company. Due to the speed of the growth, Bluetron sometimes faces difficulties coping with this increase in demand. Therefore, the company recognizes that there is a necessity for improvement in its processes. This necessity motivates the need for this research.

1.2.2 Action Problem

Currently, Bluetron experiences an average throughput time of the tape drive test process that is too high from their point of view. With ‘too high’ we mean higher than the throughput time Bluetron has agreed on with Customer X. In other words, the throughput time is higher than Customer X expects from Bluetron. As a consequence, they occasionally have to deal with delayed deliveries to Customer X, which causes Customer X to be unsatisfied with the service that Bluetron delivers. This is a case Bluetron wants to avoid since its main objective is customer satisfaction. They point out that the unpredictable demand and the dependency on other actors in the process make it challenging to guarantee on-time delivery to Customer X. They, however, also point out that these factors are not mainly the cause of the throughput being higher than Customer X expects. They emphasize that the process that is primarily carried out by Bluetron, the part of the process that is not dependent on demand or other actors, has a lot of opportunities to improve. The company sees a clear discrepancy between the norm and reality which they would like to bridge by decreasing the throughput time.

The action problem that we want to solve with this research is thus: The throughput time of the tape drive test process is higher than expected.

1.2.3 Problem Cluster

To solve the action problem, we identify additional underlying problems that cause it. To discover all the problems, we have conducted semi-structured interviews with the employees involved with the test process of tape drives and performed cross-sectional observations of the tape drive test process. These problems are in some way all related to throughput time. These problems are visualized in the problem cluster shown in Figure 1 which shows causal relationships between the different problems present at Bluetron.

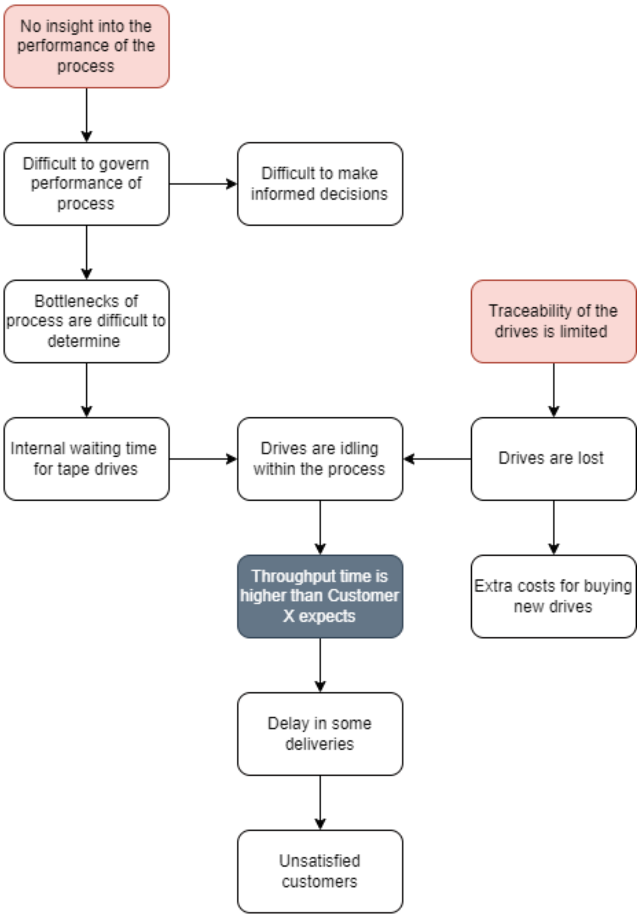


Figure 1 Problem Cluster

Figure 1 shows that the action problem causes problems such as delayed deliveries and is caused by problems itself such as idling tape drives. The action problem is that the throughput time is higher than Customer X expects. A direct consequence is that Customer X has to do business with fewer tape drives than expected. This is not the desired situation for Customer X, which leads to them being unsatisfied with the services of Bluetron.

The throughput time is affected by a variety of different problems. The most direct cause is that drives are idling within the process. We identified two causes for this: one being the internal waiting time for drives, and the other being tape drives that are lost in the system. The internal waiting time translates into drives that are waiting for the next step to happen. An example of this includes tape drives that are on a pallet ready to be shipped to Partner Y, but have to wait for the approval of Partner Y. These tape drives are thus idling. Drives being lost in the system are drives that are at a certain place of the process according to the ERP system, while in reality they are not there. This is caused by issues with traceability of the drives in the system which results in Customer X thinking these lost drives are present at Bluetron. Bluetron is therefore obliged to deliver these drives, even though Bluetron does not possess them. This leads to Bluetron having to buy new tape drives to cover for the lost drives. This consequently leads to extra costs, which a company wants to avoid.

As internal waiting time resembles the bottleneck effect of a process (Dauzère-Pérès & Zhan & Chang, 2013), a solution to resolve this waiting time would be to remove the bottlenecks. The problem is, however, that the company does not know exactly where the bottlenecks occur in the tape drive test process. This is in turn caused by the fact that it is difficult to govern the performance of the process. The performance of a process is communicated through key performance indicators (KPIs), which are measurable indicators that support success measurement (Armstrong, 2017). If the performance in terms of process-related KPIs is not known, it is also not possible to see where the performance is the worst and to locate the bottlenecks.

Finally, the difficulty to govern the performance is caused by the company not having insight into the performance of the tape drive test process. This makes it difficult for the management or responsible employees to find the information that they need and to make informed decisions.

1.2.4 Core Problem

From this problem cluster, we can derive two possible core problems: 'No insight into the performance of the tape drive test process', and 'Traceability of the drives is limited'. Since we have two problems to choose from, we have to assess which problem has the biggest impact on the action problem. After problem cluster analysis and discussion with the company the following core problem has been prioritized:

'No insight into the performance of the process'

Performance is still a broad term and we therefore specify it as performance of the process in terms of bottlenecks. Currently, this is the problem with the highest priority. By solving this problem performance can be better governed, bottlenecks can be determined, and internal waiting times can be decreased. Together this can result in a lower throughput time and a higher satisfaction for Customer X.

1.2.5 Norm and Reality

The core problem shows a clear discrepancy between norm and reality. This research aims to bridge the gap between this norm and reality. The reality is derived from the core problem: there is no insight into the performance of the test process. The norm is the opposite of this reality: there is insight into the performance of the test process. This discrepancy is difficult to measure, and therefore we will determine indicators to make it measurable. The following section discusses these indicators which make the problem quantifiable.

1.2.6 Problem Quantification

To make the discrepancy between norm and reality measurable, we have constructed quantifiable measures. These quantifiable measures have been used to determine the success of the solution by measuring the values before and after the implementation of the solution. The next paragraphs will explain the three quantifiable measures for the norm and reality.

The first objective is the effectiveness with which employees can gather insights into the bottlenecks of the process as perceived by the employees. In their research, Sundqvist, Backlund, and Chronéer (2014) attempt to define 'effectiveness', which they do as 'doing the right things'. We adjusted the definition of effectiveness to our research, namely to (1) the completeness of the data that is generated during the test process, (2) the ability to clearly interpret the information about the test process, and (3) the ability to convey complete insight into the bottlenecks of the process.

The second objective is the efficiency with which employees at Bluetron can gather insights about the bottlenecks of the tape drive test process as perceived by the employees. Sundqvist, Backlund, and Chronéer (2014) define 'efficiency' as 'doing things right'. Again, we adjusted the definition of efficiency to our research, namely to the time consumed by employees in gathering insight into the bottlenecks of the tape drive test process.

The third objective is the ability of the dashboard prototype to support locating bottlenecks in the tape drive test process at Bluetron. With the support of the prototype solution, we have attempted to locate a bottleneck and to thereafter eliminate this suspected bottleneck by making an intervention in the tape drive test process. To measure whether we have eliminated a real bottleneck, we calculate the difference in average throughput time of the tape drives between June and September, before and after the intervention has been made.

1.3 Research method

1.3.1 Problem-solving Approach

To solve the problem 'There is no insight into the performance of the test process', we have chosen to create a dashboard. Since the aim of dashboards is to increase the understanding of data (Strugar, 2020; Few, 2006; Bach, 2020), we believe it to be a suitable solution to the core problem. To do this, we have followed the Design Science Research Methodology (DSRM), a method oriented toward the creation of successful artifacts (Peffers et al., 2007). This methodology consists of six steps, as Figure 2 shows.

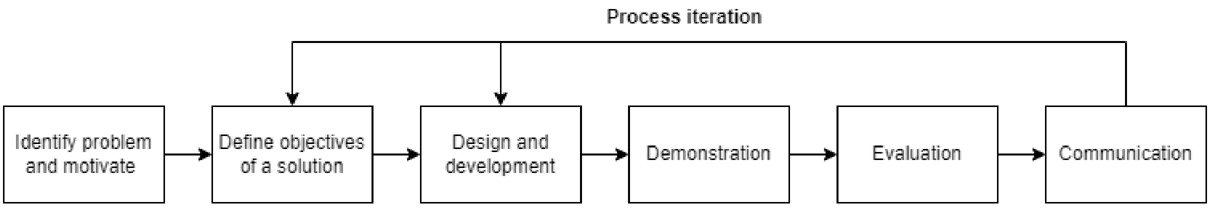


Figure 2 Steps of the DSRM (Peffers et al., 2007)

The first step is already executed in the first phase of the research, namely in section 1.2 'Problem Identification'. We identified the problem using semi-structured interviews and cross-sectional observations. The second step of the DSRM is defining a solution's objectives, which was already done in section 1.2.6 'Problem quantification'.

'Design and development' is the third step of the DSRM and we have executed this step in three phases. Phase 1 consists of analyzing the current situation at Bluetron. We have looked at the test process of the tape drives and explained the different steps in a structured way. Moreover, we have looked at the insights Bluetron currently has into the performance of the process in terms of KPIs by analyzing the ERP system and the BI platform. In phase 2 we have looked at the literature about KPI selection and KPI visualization to determine a suitable method to identify and select KPIs, as well as to determine criteria for the visual representations of these KPIs. The last phase of the 'Design and Development' step consists of identifying, selecting, and visualizing KPIs using the prior chosen KPI selection and visualization methods.

'Demonstration' is step 4 of the Design Science Research Methodology and we have executed this step by testing a prototype solution to demonstrate the concepts we developed. After the creation of the design and the testing of the prototype design solution, we executed step 5 of the DSRM, 'Evaluation'. This step includes the evaluation of the prototype solution in terms of the satisfaction of Bluetron employees with the design and the ability of the dashboard to locate bottlenecks. The last step is a presentation of the research, which is in the form of a written thesis and a presentation given at the end to the company supervisor and the university supervisor. By executing these steps, we have attempted to solve the core problem.

1.3.2 Scope

This study aims to create a dashboard design that provides insight into the performance of the test process of tape drives at Bluetron. Performance is still a very broad term, so we have specified it as the performance of the test process of tape drives in terms of bottlenecks. This means the focus of this study lies on the bottlenecks of the test process and distinctive forms of performance have not been dealt with. The studied population is the test process of tape drives at Bluetron, which means the research is limited to Bluetron and in particular to the Bluetron employees that will use the outcomes of this research. Next to that, the scope of this research is based on the available data at Bluetron. If certain KPIs do not have registered data, we either cannot use it or we will have to generate the data ourselves. Moreover, it is beyond the scope of this research to perform a longitudinal observation of the working of the dashboard design at Bluetron. We have limited ourselves to the perception the employees have that the dashboard prototype will improve the situation, and to the ability of the dashboard prototype to locate bottlenecks in the tape drive test process.

1.3.3 Deliverables

As a result of the problem-solving approach, we have produced several deliverables.

1. The analysis of the test process of the tape drives has brought about 6 Business Process Modeling Notation (BPMN) models showing all the different steps of the tape drive test process divided into 6 stages.
2. The analysis of the ERP system and the BI platform has led to a list of available KPIs concerning the test process of tape drives at Bluetron. These first two deliverables give an overview of the current situation.
3. The literature study together with the KPI selection and the KPI visualization have resulted in visual representations of the selected KPIs. Moreover, a dashboard prototype has been created.
4. The literature study on dashboard views has resulted in a single dashboard view displaying the visual representations of the selected KPIs.
5. In this research, an attempt has been made to implement this prototype design solution based on the findings of the thesis, after which we have evaluated this prototype-based design solution. This evaluation has resulted in a list of recommendations on the use of the dashboard design.
6. Finally, we have reported on the outcomes of this research in the written thesis and we will verbally report the outcomes through a presentation at the colloquium.

1.4 Research Questions

1.4.1 Main Research Question

The purpose of this research is to solve the core problem 'There is no insight into the performance of the test process'. This research is limited to the performance of the test process of tape drives in terms of bottlenecks. As the aim of dashboards is to increase the human comprehension of data

(Strugar, 2020; Few, 2006; Bach, 2020), we formulated the following main research question to solve the core problem:

'How can the bottlenecks in the tape drive test process be detected using a dashboard?'

1.4.2 Sub Questions

In the following section, we describe the knowledge questions for each DSRM step. As was mentioned in section 1.3.1 'Problem-solving Approach', steps 1 and 2 of the DSRM are already executed in the first part of the research. We will therefore start with step 3 of the DSRM.

Step 3 of the DSRM is 'Design and Development', which includes the design and development of the artifact we have created. To complete this step, 6 questions have been answered. First we have analyzed the test process of tape drives at Bluetron with as a result 6 BPMN models of the tape drive test process. The first question we ask is the following:

1. *'What does the current test process of tape drives at Bluetron look like?'*

After 6 BPMN models were created for the test process of tape drives, we analyzed the insights Bluetron currently possesses into the bottlenecks of the test process. We have done this by analyzing the available KPIs. Moreover, we have also analyzed the effectiveness and efficiency with which the employees can gather insights into the bottlenecks of the tape drive test process without the dashboard prototype. The second question we therefore ask is the following:

2. *'What insights into the bottlenecks of the test process does Bluetron currently have?'*

By answering the two previous questions, we have attempted to create an overview of the current situation at Bluetron concerning the test process of tape drives. The literature study on KPI selection methods was the next step of this research to discover relevant methods that can be used in this research. For this purpose, the third question is formulated:

3. *'What is a relevant method to select KPIs for the dashboard design?'*

After the first literature study on KPI selection methods, we have carried out a second literature study to discover relevant criteria for the visualization of KPIs. For this reason, we ask the fourth question of step 3 'Design and Development':

4. *'What are the criteria for choosing relevant visual representations for KPIs?'*

To finalize the third phase of the DSRM, we have used the chosen KPI selection method and the KPI visualization methods to prioritize, select, and visualize KPIs. The last two questions we ask for this phase are the following:

5. *'What are the most relevant KPIs for the dashboard for Bluetron that measures and monitors bottlenecks?*
6. *'What are relevant visual representations for the KPIs selected for the KPI dashboard?'*

With the completion of step 3 of the DSRM, we have addressed step 4 'Demonstration'. In this part of the research, a dashboard design has been created displaying the KPI visualizations as chosen in the previous phase of the research. The seventh question is the following:

7. *'How can the visualizations for the different KPIs that we have chosen for the bottlenecks be combined in a dashboard view to enable effective monitoring?'*

After the creation of the dashboard design and the dashboard prototype, we have attempted to promote a supportive attitude towards this prototype at Bluetron, guided by the following question:

8. *'How can we promote a supportive attitude towards the introduction of the KPI dashboard?'*

Step 5 'Evaluation' is the step that we addressed next. After the implementation of the prototype solution, it was necessary to evaluate this prototype solution. To determine whether the dashboard design complies with the objectives, we ask the following question:

9. *'Did the prototype built following the guidelines of this thesis comply with the objectives we have set, namely effectively and efficiently detecting bottlenecks in the tape drive test process?'*

When all these questions are answered, we can answer the main research question. The last step of the DSRM is step 6 'Communication'. To complete this step, there is no need to formulate a knowledge question. We have reported on our findings in the thesis and we will verbally report on our findings through a presentation at the colloquium.

In this thesis, the terms 'KPI dashboard' and 'dashboard design' for the monitoring and analysis of bottlenecks are employed interchangeably. This is based on the understanding that the dashboard functions as our design artefact within the framework of the Design Science Research Methodology.

1.5 Research Design

The following section discusses the design of this research. Table 1 shows the details of the research design. The first column of the table shows the different sub-questions explained in section 1.4.2 'Sub questions'. Each row explains the research design of the sub-question mentioned in column 1 of that row. Columns 2, 3, 4, 5, 6, and 7 respectively show the number of the chapter containing the answer to the question, the research target, the research population, the research methodology, the method of data gathering, and the method of data processing belonging to the sub-question. Following Table 1, we describe the activity plan for each knowledge question. The activity plan elaborates on the activities we have carried out to answer the question according to the research design.

Knowledge Question	Chapter w. Answer	Research Target	Research Population	Research Methodology	Method of Data Gathering	Method of Data Processing
1. What does the current test process of tape drives at Bluetron look like?	2	Test process	Operations employees, Backoffice employees	Qualitative	Cross-sectional observation, Semi-structured interviews	BPMN model
2. What insights into the performance of the test process does Bluetron currently have?	2	Test process	ERP system, BI platform, Backoffice employees, Operations employees	Qualitative, Quantitative	Cross-sectional observation, Structured interviews, Analyzing ERP system, Analyzing BI platform	List of available KPIs with the place of storage, Graphs of initial values of the objectives of the prototype solution
3. What is a relevant method to select KPIs for the dashboard design?	3	Literature	Academic databases	Qualitative	Literature study	Descriptive text about the relevant KPI selection methods, Comparison between KPI selection methods, Descriptive text about the most suitable KPI selection method
4. What are the criteria for choosing relevant visual representations for KPI dashboards?	3	Literature	Academic databases	Qualitative	Literature study	Descriptive text about the criteria for choosing relevant visual representations
5. What are the most relevant KPIs for the dashboard for Bluetron that measures and monitors bottlenecks?	4	Test process, Literature	Academic databases, Backoffice employees, Operations employees, ERP system	Qualitative, Quantitative	Literature study, Semi-structured interviews, AHP with SMART goal-setting theory, KPIs from ERP system	List of KPIs to integrate into the dashboard design,
6.What are relevant visual representations for the KPIs selected for the KPI dashboard?	4	Test Process	Backoffice employees, Operations employees, BI platform	Qualitative	Visual representations determined with question 4	Visual representations of the KPIs chosen for the dashboard design
7. How can the visualizations for the different KPIs that we have chosen for the detection of bottlenecks be combined in a dashboard view to enable effective monitoring?	5	Test process, Literature	Databases, University supervisor, ERP system, BI platform	Qualitative, Quantitative	Literature study, Visual representations from question 5, KPIs from ERP system	Descriptive text about organizing visualizations in a dashboard, Dashboard Design, Prototype version of dashboard
8.How can we promote a supportive attitude towards the introduction of the KPI dashboard?	6	Test process, Literature	Databases, Backoffice employees, Operations employees	Qualitative	Literature study, Semi-structured interviews	Descriptive text about implementation plans, Implementation plan

9. Did the prototype built following the guidelines of this thesis comply with the objectives we have set, namely effectively and efficiently detecting bottlenecks in the tape drive test process?	7	Test process	Operations employees, Backoffice employees	Qualitative, Quantitative	Semi-structured interviews, Structured interviews in the form of surveys, Retrieving data from BI platform	Graphs of new values of the objectives of the prototype solution after implementation, Table with throughput times before and after intervention

Table 1 Research Design

1.5.1 Activity Plans

The following paragraphs will describe the activities we have executed to answer the sub questions that we formulated for this research. To answer the first knowledge question '*What does the current test process of tape drives at Bluetron look like*?', we have started with cross-sectional observations of the operations part and the back office part of the test process of tape drives. To clarify, the operations part of the test process is the work executed by the repair engineers in the workshop, and the back office part of the test process is the work done by the planners in the back office. The next step was to conduct unstructured interviews based on the observations with the supervisor of the repair engineers, the operations manager, the planner of the test process, and the business consultant, to account for any questions we might still have had about the tape drive test process. Based on the observations and interviews, we have constructed 6 BPMN models that give an overview of the tape drive test process.

To find an answer to the second knowledge question, '*What insights into the performance of the test process does Bluetron currently have?*', we have first analyzed the ERP system and the BI platform that Bluetron operates with. We have gathered all available KPIs that are currently available and are already calculated. Following this action, we have made a structured overview of the available KPIs and the places where these KPIs are stored. Secondly, we have conducted structured interviews with both back office and operations employees to determine the initial values of the objectives 'effectiveness' and 'efficiency' we have set for the solution which are explained in Section 1.2.6 'Problem Quantification'. We have visualized these values in a table to gain an understanding of the initial situation concerning the effectiveness and efficiency with which employees at Bluetron can gain insight into the bottlenecks of the tape drive test process.

The third and fourth question both have required us to perform a Systematic Literature Review. For both questions, this has included defining inclusion and exclusion criteria, identifying academic databases, describing search terms, performing the search, constructing a conceptual matrix, and finally integrating the theory. This has resulted in an overview of relevant KPI selection methods and criteria for KPI visualizations. When the Systematic Literature Review on KPI selection methods was performed, we have compared the KPI selection methods and we have chosen the most relevant method to be used during the next phase of the research. When the Systematic Literature Review on KPI visualizations was performed, we have stated the criteria for the visual representations for this research.

To answer question 5, KPIs had to be selected. We have carried out a literature review to start with the identification of test-related KPIs. Next to this literature review, we have conducted semi-structured interviews with both back office and operations employees to gather their perspectives on the identification of relevant KPIs for the dashboard. When the identification of KPIs was completed, we have used the Analytic Hierarchy Process in combination with the SMART goal-setting theory to prioritize and we have selected KPIs that are visualized on the dashboard. The reason why we chose this method is explained in Section 3.1 'KPI Selection Methods'.

To answer question 6, visual representations had to be chosen for the selected KPIs. To visualize these KPIs, the visual representation criteria resulting from question 4 'What are the criteria for choosing relevant visual representations for KPI dashboards?' have been used to choose suitable visualizations for the selected KPIs.

Question 7 '*How can the visualizations for the different KPIs that we have chosen for the bottlenecks be combined in a dashboard view to enable effective monitoring*?' has been primarily answered through a literature study. Based on this literature study, we have created a dashboard design using the KPI visualizations resulting from question 6 and a prototype solution of this dashboard has been developed.

We answered question 8 '*How can we promote a supportive attitude towards the introduction of the KPI dashboard*?' primarily through a Systematic Literature Review on implementation plans. Based on this review, we have chosen and explained a suitable implementation plan based on the change model by Kotter (1995) for the dashboard prototype design at Bluetron.

After the testing of the prototype solution, we have evaluated the dashboard prototype design to answer question 9. The prototype solution has been evaluated in terms of its capabilities to meet the objectives we have set. These objectives have already been determined and are explained in section '1.2.6 Problem Quantification'. We have conducted structured interviews in the form of surveys with both back office and operations employees to determine the final values of the first two objectives, namely the perception of the employees about (1) the effectiveness and (2) the efficiency of the dashboard prototype. Moreover, to determine whether the dashboard is successful in providing the ability to locate bottlenecks, we have attempted to locate a bottleneck with the support of the dashboard prototype. By analyzing the average total throughput times we determined whether the dashboard was successful in supporting Bluetron to locate bottlenecks in the tape drive test process.

1.6 Theoretical Perspective

The purpose of this research is to solve the problem that there is no insight into the performance of the test process of tape drives. This problem accounts for not being able to identify bottlenecks in the tape drive test process. Therefore, we have been exploring theories that are capable of giving insight into data.

Business Intelligence is about collecting correct data and communicating the correct results to the right people for decision-making purposes (Frolick & Ariyachandra, 2006). Data interpretation methods commonly used for business intelligence are balanced scorecarding and dashboarding (Bentley, 2017). Dashboards are software systems that aim to increase human understanding of data to support effective decision-making (Strugar, 2020). Balanced Scorecard is a business intelligence tool to cope with performance monitoring, evaluation, and forecasting, and the tool is mostly utilized to manage and control the performance of business processes (Yanine & Córdova & Durán, 2020). The difference between balanced scorecards and dashboards is reflected in the measurement of data: dashboards display real-time data, whereas scorecards display periodic data (Smith, 2003). Bluetron desires decision-making based on real-time data. This research, therefore, focuses on dashboards and their functionalities. There are also other methods to locate bottlenecks, for example Lean and Six Sigma, which are frequently used methods often used as combination (Womack & Jones, 1997; Schroeder et al., 2007; Smith, 2003). However, as the focus of this research is on creating insight into the bottlenecks and not to eliminate them, we will not use these theories. Lean and Six Sigma can serve as theories for future research at Bluetron, when the bottlenecks have to be eliminated.

According to Molina-Carmona et al., the number of key performance indicators displayed on a dashboard must be minimal, and the critical aspect of dashboards is the selection of suitable KPIs (2018). There are multiple methods available in the literature to select KPIs. Frequently used methods are the Delphi method, the Analytic Network Process, and the Analytic Hierarchy Process (Saaty, 1988; Liu & Tsai, 2007; Barber et al., 2023). Less frequently used methods are the DEMATEL method, the Best-Worst Method, the ELECTRE, and the Interpretative Structural Modeling method (Seker & Zavadskas, 2017; Moktadir et al., 2021; Goncalves, Dias & Machado, 2014; Amrina &

Yulianto, 2018). In this research, we deploy the AHP due to academic relevance, time constraints and a relatively low dependency on expert opinions. This method is used in combination with the SMART goal-setting theory, because of the ability of the method to set clear and measurable goals (Shahin & Mahbod, 2007).

The dashboard design displays visual representations of the selected KPIs with the use of Visual Analytics. Visual Analytics uses tools and processes to analyze data using visual representations of the data (Keim, Mansmann & Thomas, 2010). The aim of the dashboard is to create insight into the bottlenecks of the process, and therefore Visual Analytics is a significant subject for this thesis. Lebanon and El-Geish (2018) discuss in their research various types of plots that can be used for KPI visualizations. Stoltzman (2018) and Zelazny (2001) connect these visualizations with the aim of the representations. We use these theories to choose suitable visual representations. Shneidermann (1996) and Halim and Tufail (2017) have also shared theories about visual representations in terms of data types and evaluative metrics. We have chosen not to use these theories as they do not fit in the scope of this research.

The chosen visual representations are put together in a dashboard view. Yigitbasioglu and Velcu (2012) discuss in their research two different features of dashboards: functional and design features. Eckerson (2005) and Dinmohammad and Wilson (2021) share theories about functional features and these theories have been used when creating the dashboard design. Few (2006) has been a very important researcher in the field of dashboard designing and he discusses various mistakes generally made when designing dashboards. During the design process we have attempted to avoid these mistakes. Bach (2023) has described tradeoffs that concur with dashboard design. We have evaluated these tradeoffs for the design of the dashboard.

The dashboard design will have to be accepted at Bluetron. Because Garvin (2000) argues that the implementation of a technical artifact is heavily dependent on employee acceptability, we have chosen to focus on change models with an emphasis on employee acceptability. Three frequently mentioned change models are the model by Jick (1991), the model by Kotter (1996), and the model by General Electric (Garvin, 2000). Due to academic relevance and the incorporation of short-term wins into the model, we have used the model by Kotter (1996) to guide the employee acceptance process.

With this theoretical framework, we give an overview of the theories that have been relevant for this research.

Chapter 2 Current Situation

This chapter discusses the current situation of the tape drive test process at Bluetron. We conducted unstructured interviews with multiple employees involved with the process to construct BPMN models of this process which are shown in Section 2.1 ‘Process’. Next, in Section 2.2 ‘Available KPIs’, we analyzed the BI platform to create a list of currently available KPIs. Lastly, we conducted a survey among four employees to determine the initial values of the first two objectives we have set in Section 1.2.6 ‘Problem Quantification’. These initial values can be found in Section 2.3 ‘Initial Values Objectives’.

2.1 Process

This section discusses the tape drive test process at Bluetron in detail. We have gathered information about the process by performing cross-sectional observations of the tape drive test process and thereafter conducting unstructured interviews with multiple employees that are involved with the tape drive test process. We discovered that tape drives can follow multiple paths within the process which is dependent on the type of tape drive and test results. A single BPMN model of the process has proven to be complex and difficult to read. We have therefore decided to divide the process in 6 stages and have thus constructed 6 BPMN models. These BPMN models consist of different pools and different lanes. The pools represent the different companies and the lanes represent different actors within a company. We have chosen to assign colors to the different actors within Bluetron to provide clarity during the analyzing of the models. The list below shows the 6 stages of the test process.

1. Receiving and Distributing
2. Testing
3. Repairing
4. Partner Y
5. Checking
6. Returning

These stages will be explained in further detail in the following paragraphs.

1. Receiving and distributing

The first stage is the receipt and distribution of the tape drive by the logistics department of Bluetron. Customer X initializes the process by notifying Bluetron that tape drives will arrive within a certain amount of time, which is unknown upfront. The distribution of the tape drives to the workshop or the repair department depends on the type of tape drive. Customer X has determined that Bluetron is authorized to test the defect tape drives and that the repairing is outsourced to Partner Y. These types of tape drive will go to the workshop. For some types of tape drives, however, Customer X has made an exception. For these types Bluetron has the authorization to repair them itself. These types of tape drive will go to the repair department. When the first stage is completed, it thus either triggers the start of Stage 2 Testing or the start of Stage 3 Repairing. Figure 3 shows the BPMN model of the first stage of the test process.

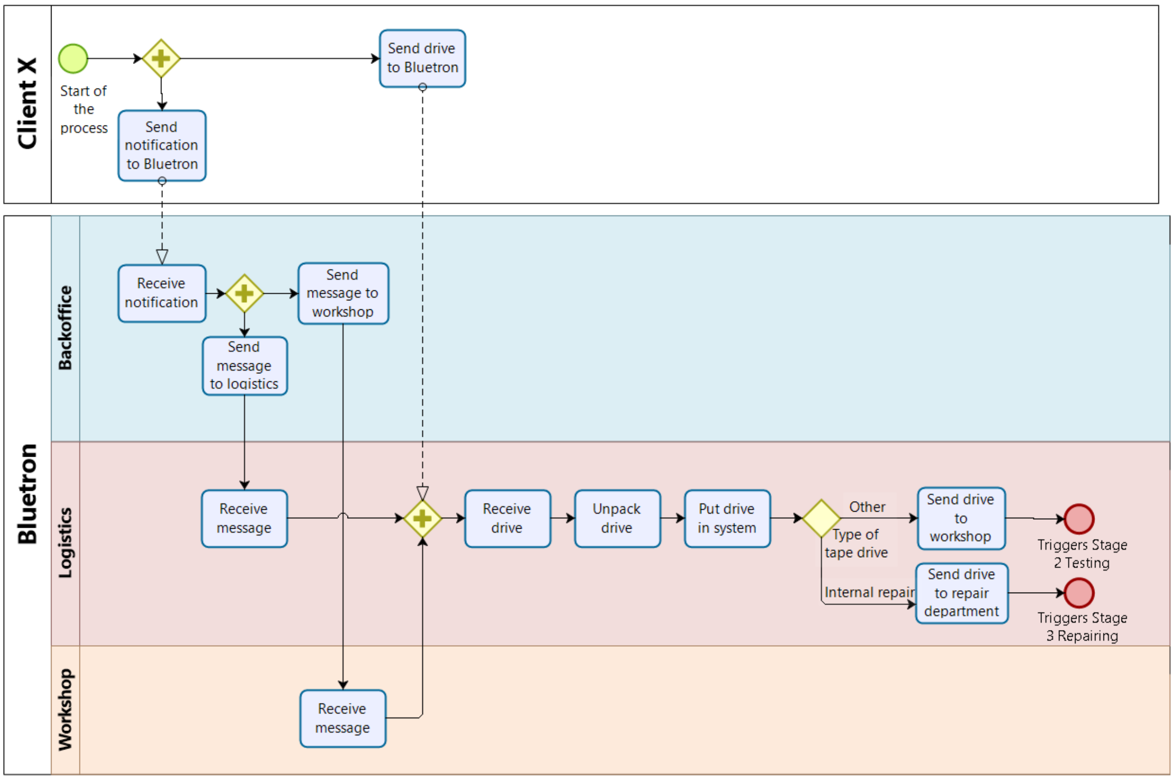


Figure 3 BPMN model of Stage 1 Receiving and Distributing

2. Testing

Stage 2 of the test process consists of testing procedures and can only be triggered by Stage 1 Receiving and Distributing. Stage 2 can trigger 2 other stages: Stage 4 Partner Y and Stage 6 Returning. Figure 4 shows the BPMN model of the second stage of the process. Multiple tests are performed during this stage, e.g. the NDF test and the library test. We will not go into detail about these tests, since the technical contents of these tests do not contribute to this research.

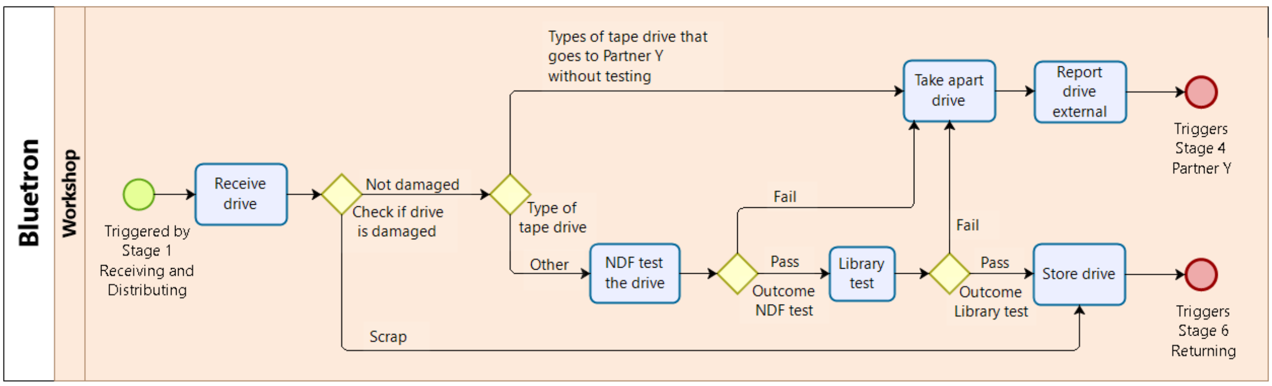


Figure 4 BPMN model of Stage 2 Testing

3. Repairing

Stage 3 consists of the repair of tape drives and is triggered by the completion of Stage 1 Receiving and Distributing. The stage can only trigger the last stage of the process, Returning. This stage and the data generated during this stage are not included in the scope of this research, but we decided to explain the activities for the sake of completeness. Figure 5 shows the BPMN model of the third stage of the process.

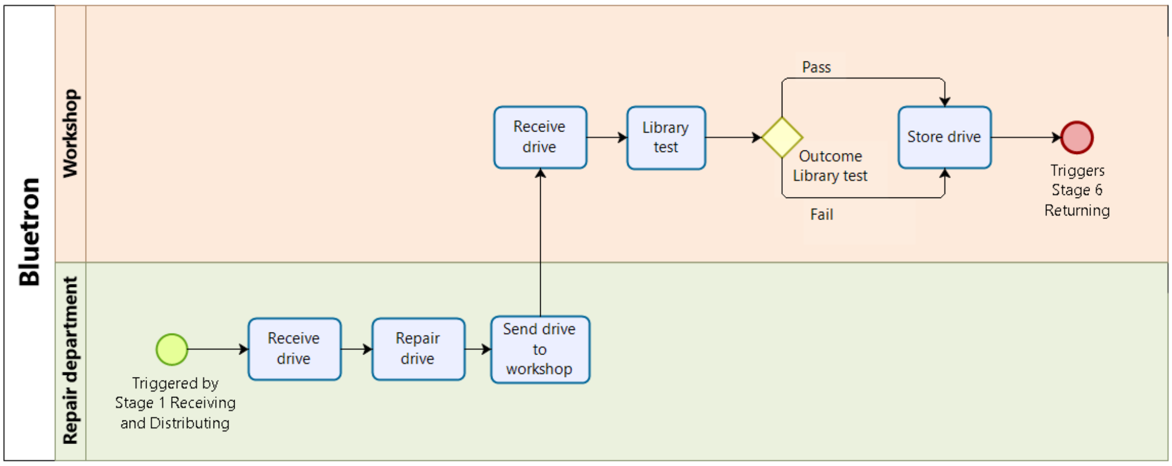


Figure 5 BPMN model of Stage 3 Repairing

4. Partner Y

The fourth stage of the process involves the outsourcing of the repair of tape drives to Partner Y. The stage is triggered by either stage 2 Testing or stage 3 Repairing. The completion of stage 4 triggers the fifth stage of the process, Checking. Not all the activities performed by Partner Y are known and the BPMN model in Figure 6 thus shows the activities performed by Partner Y in a simplified manner.

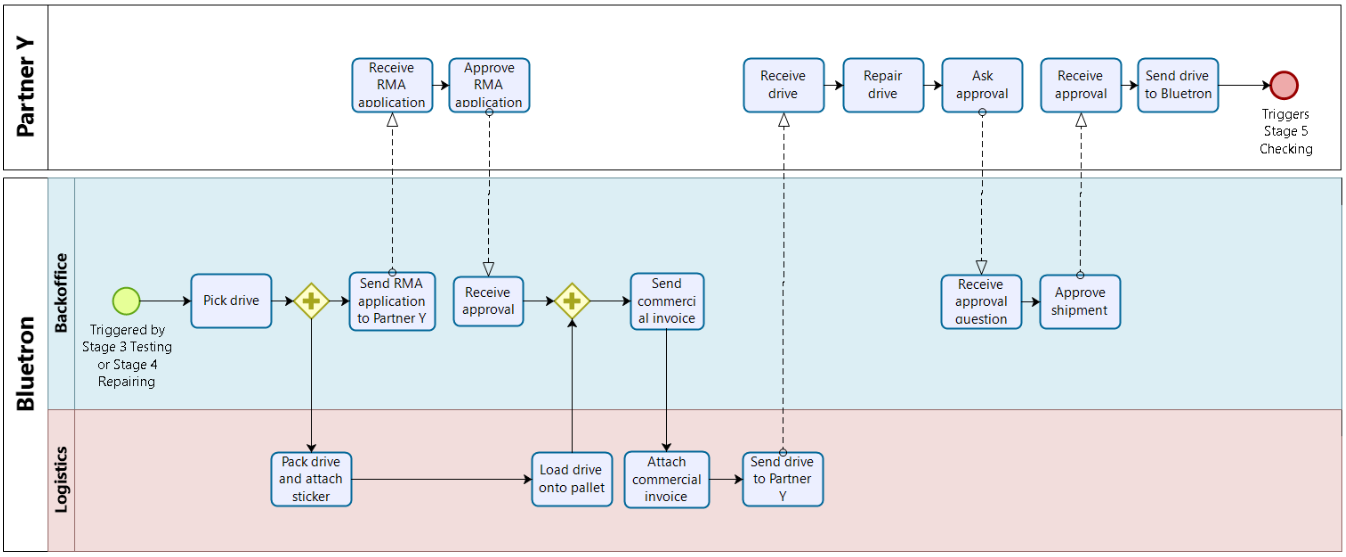


Figure 6 BPMN model of Stage 4 Partner Y

5. Checking

Stage 5 Checking is triggered by the completion of stage 4 Partner Y and involves checking whether or not Partner Y has been successful in repairing the tape drive. When Partner Y has succeeded, stage 6 Returning is triggered. When Partner Y has failed, the tape drive will return to Partner Y under warranty, because stage 4 is triggered for the second time. Figure 7 shows the BPMN model of stage 5 Checking.

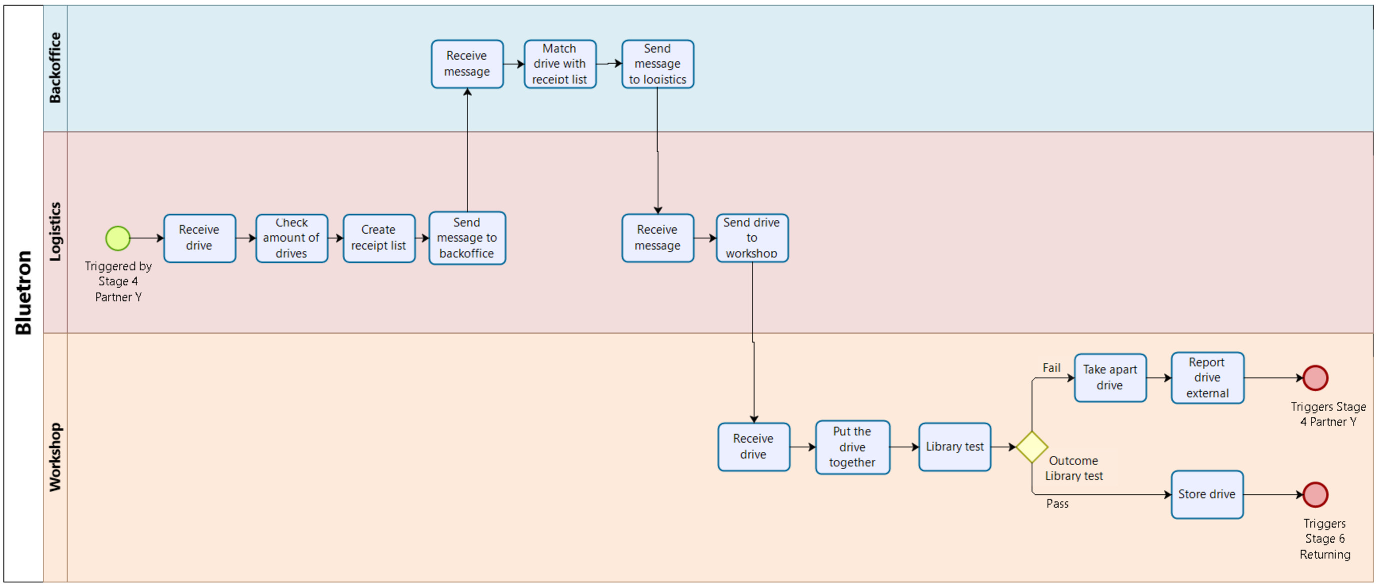


Figure 7 BPMN model of Stage 5 Checking

6. Returning

The last stage of the test process is Returning and consists of preparing the tape drives to be picked up by Customer X at Bluetron. The stage is either triggered by stage 2 Testing or stage 3 Repairing or stage 5 Checking. With the completion of stage 6, the entire test process is completed. Figure 8 shows the BPMN model of the last stage of the test process.

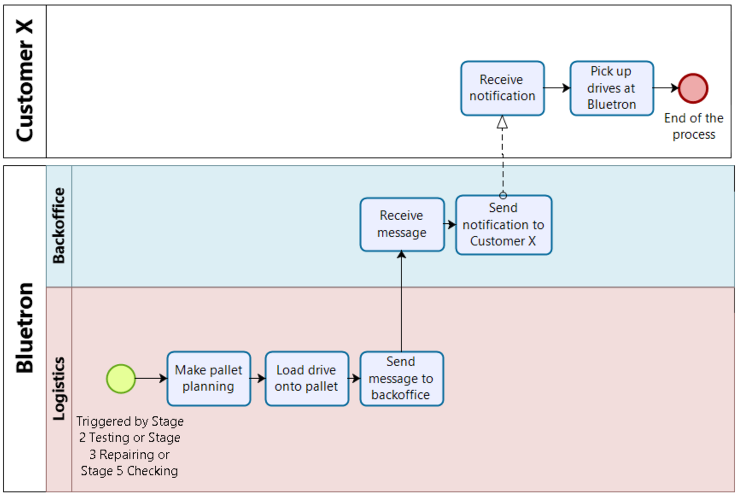


Figure 8 BPMN model of Stage 6 Returning

The BPMN models used to visualize the tape drive test process have played a significant role in bringing clarity to this complex process. By visually representing each step and decision point, they provide a structured overview that supports the understanding of the complexities of the test process.

2.2 Available KPIs

To discover what insight Bluetron currently has in the performance of the tape drive test process, we have created a list of KPIs that employees already have access to. We have done this by analyzing the ERP system and the BI platform that Bluetron uses. The KPIs that we have discovered are not shown on a dashboard, but on different sheets in the BI platform. Based on an interview with the company supervisor where we discussed the meaning of these KPIs, Table 2 was created. This table shows the KPIs in the first column and the definition of these KPIs in the second column.

Table 2 Available KPIs

KPI	Definition
NDF Fail	The number of tape drives per unit of time which fail the NDF test.
NDF Pass	The number of tape drives per unit of time which pass the NDF test.
Extern	The number of tape drives per unit of time which are admitted as 'extern' in the ERP system, which means they failed the NDF test and will be shipped to Partner Y for repair.
Packed	The number of tape drives per unit of time which are packed to be shipped to Partner Y.
No NDF	The number of tape drives per unit of time which do not need an NDF test and will directly be shipped to Partner Y.
Test by fail reason	Failed tests per time unit together with the reason of failure.
NDF pass/fail by article	The ratio between NDF Pass and NDF Fail per article.
NDF pass/fail by customer	The ratio between NDF Pass and NDF Fail per customer.
Warranty parts received	The number of products per unit of time that are received at Bluetron as warranty. Warranty means that the products have been used and during this usage, the product breaks down.
Warranty parts accepted	The number of products per unit of time that are accepted by Bluetron as warranty.
%Warranty	The number of products that are received and accepted as warranty in proportion to the total number of products that have been delivered to Customers.
DOA	The number of products per unit of time that are received at Bluetron as Dead on Arrival. Dead on Arrival means that the product was defective when the Customer received the product.

%DOA	The number of products that are received at Bluetron as Dead on Arrival in proportion to the total number of products that have been delivered to Customers.
Throughput time Pick and NDF	The time between the picking of a tape drive and the tape drive finishing the NDF test. Picking means receiving the tape drive from Customer X and registering the tape drive in the system.
Throughput time NDF and Extern	The time between the tape drive finishing the NDF test and the tape drive being admitted as 'extern' in the ERP system.
Throughput time Pick and Pack	The time between the picking of a tape drive and the drive being packed by the logistics department to send the tape drive to Partner Y for repair.

The KPIs that are discussed in Table 2 are already visualized in the BI platform of Bluetron. The KPIs 'NDF Fail' and 'NDF Pass' are together visualized with a bar chart. The KPI 'Test by fail reason' is visualized with a column chart, and the KPIs 'NDF Pass/Fail by customer' and 'NDF Pass/Fail by article' are separately visualized with bar charts. The KPIs 'Extern' and 'Packed' are together with the KPIs 'NDF Fail' and 'NDF Pass' visualized with a column chart. The three throughput times are separately visualized with line charts. Lastly, the KPIs 'Warranty parts received', 'Warranty parts accepted', '%Warranty', 'DOA', and '%DOA' are together visualized in one table.

2.3 Initial Values Objectives

The previous sections have explained the current tape drive test process at Bluetron and currently available KPIs in the BI platform of Bluetron. This section will discuss the current situation in terms of the objectives 'effectiveness' and 'efficiency', explained in Section 1.2.6 'Problem Quantification'. This information about the two objectives 'effectiveness' and 'efficiency' is used in Chapter 7 'Evaluation' to evaluate these objectives as perceived by the employees after the introduction of the dashboard prototype design. We gathered this information through a survey that was filled in by four employees. These employees are representative for all employees involved with the tape drive test process, because together they fill or have filled all positions within Bluetron regarding the tape drive test process. The survey consisted of 4 statements and the employees had to indicate to which degree they agreed with the statement on the Likert scale, where '1' means 'totally disagree', '3' means 'neutral , and '5' means 'totally agree'. Appendix A 'Survey Initial Value Objectives' shows the contents of the survey.

Effectiveness

The first objective is the effectiveness with which employees can gather insights into the bottlenecks of the tape drive test process. Effectiveness is expressed in terms of (1) the completeness of the data that is generated during the test process, (2) the ability to clearly interpret the information about the test process, and (3) the ability to convey complete insight into the bottlenecks of the process. The first three statements were used to measure this objective. The first statement is stated below:

1. *'Enough data is generated during the tape drive test process to be able to gather insight into the bottlenecks of the process.'*

Table 3 shows the scores the employees assigned to this statement. The first column shows the statement, and the second until the sixth row display the number of employees that assigned a certain score to the statement. As an example, two employees gave the score '4' to the first statement and two employees gave the score '5' to the first statement. The employees generally agree with this statement. This means that they believe that almost enough data is generated to be able to create insight into the bottlenecks of the tape drive test process.

The second statement of the survey is stated below:

2. *'The generated data is transferred to clearly interpretable information about the tape drive test process.'*

The third row in Table 3 displays the scores for this statement. Three employees score relatively low on this statement, while one employee believes that this statement is very true. It can be concluded that the employees are not in agreement which means that one employee thinks the data is very clearly interpretable, while the other employees cannot interpret the data clearly.

The third and last statement about 'effectiveness' is an extension on statement 2 and is described below:

3. *'The generated data is transferred to clearly interpretable information which gives a complete insight into the bottlenecks of the tape drive test process.'*

The difference with statement 2 is 'which gives a complete insight into the bottlenecks'. With this difference, we want to lie emphasis on, if the information is clearly interpretable, whether this information gives a complete insight into the bottlenecks of the process. Row 4 in Table 3 shows the scores for this statement. The table displays that the employees do not agree with the statement. This means that they believe that the information that is present in the BI platform of Bluetron does not provide a complete insight into the bottlenecks of the test process of tape drives. These first three statements provide the overall score for effectiveness. The conclusion for this objective is that the emphasis of this research will thus not lie on data generation, but rather on data interpretation and the ability of the dashboard to provide a complete insight into the bottlenecks of the tape drive test process.

Efficiency

The second objective is efficiency, which is expressed in terms of time consumed by employees to gather insights into the bottlenecks of the tape drive test process. To measure this objective, we included one statement in the survey, which is stated below.

4. *'I need the minimal amount of time to acquire clearly interpretable information which gives insight into the bottlenecks of the tape drive test process.'*

The fifth row of Table 3 displays the scores the fourth statement. It becomes apparent that the employees believe that the current situation with regard to gathering insights about the bottlenecks of the process is not efficient and that there is room for improvement. It can be concluded that the emphasis of the research should thus also be on increasing efficiency by decreasing the time needed to gather an insight into the bottlenecks of the process.

Table 3 Scores given by employees at Bluetron for the four statements of the survey about effectiveness and efficiency of the current situation at Bluetron

Statement	1	2	3	4	5
1.Enough data is generated during the tape drive test process to be able to gather insight into the bottlenecks of the process.	-	-	-	2	2
2.The generated data is transferred to clearly interpretable information about the tape drive test process.	-	3	-	-	1
3.The generated data is transferred to clearly interpretable information which gives a complete insight into the bottlenecks of the tape drive test process.	3	1	-	-	-
4. I need the minimal amount of time to acquire clearly interpretable information which gives insight into the bottlenecks of the tape drive test process.	2	2	-	-	-

With this start evaluation, the employees have shared their opinions and beliefs about the current situation at. The conclusion of this start evaluation is that the emphasis of this research will lie on data interpretation and the completeness of the information about the bottlenecks of the test process. Moreover, the dashboard should decrease the time needed to gather insights into the bottlenecks of the process.

Chapter 3 Literature Review

To gain knowledge about KPI selection methods and KPI visualization choices, we have performed Systematic Literature Reviews on these topics. This chapter discusses these Systematic Literature Reviews and the findings of these reviews. Section 3.1 'KPI Selection Method' describes the findings of the literature review about KPI selection methods and Section 3.2 'KPI Visualization Choices' describes the findings of the literature review about KPI visualizations.

3.1 KPI Selection Method

The purpose of this research is to create insight into the bottlenecks of the test process of tape drives at Bluetron. We made an attempt to do this by creating a dashboard design that shows the most relevant information about the bottlenecks of the tape drive test process. This information is communicated through key performance indicators (KPIs), which are measurable indicators of performance that support progress tracking and success measurement (Armstrong, 2017). The dashboard must display a minimal number of KPIs and the selection of suitable KPIs is critical for a successful dashboard (Molina-Carmona et al., 2018). In practice, however, selecting suitable KPIs from an extensive list of potential KPIs is a complex task (Cai et al., 2009). This literature review will explore different methods to select KPIs and elaborate on these methods. Appendix B 'SLR KPI Selection Methods' shows the approach for this Systematic Literature Review.

From organization to organization, the most relevant KPIs are generally different, due to the organization's preferences (Marr, 2012). That is why a frequently used method to identify KPIs is to ask for the opinion of experts in the field the organization is active in. This method is mostly used together with a literature review to determine KPIs, after which the experts share their opinion on the most relevant KPIs (Dwivedi & Madaan, 2020; Spackman et al., 2019; Ho, Lai & Chiu, 2021).

The second method we identify is the Delphi method, which Barber et al. (2023) used with input KPIs from a literature review and expert opinions. The Delphi method can be combined with other methods, yet it can also be used on its own to select KPIs (Salgado et al., 2020). Pokhrel et al. (2023) combined the Delphi method with a complementary method, namely the PROMETHEE.

Another popular method to select KPIs is the Analytic Hierarchy Process (AHP), which was used by Anjomshoae, Hassan, and Wong (2019) as the main method to choose relevant KPIs. The AHP can be employed on its own, but is regularly combined with a literature review (Kusrini, Safitri & Fole, 2019; Kant & Gupta, 2022). The AHP is also regularly combined with the SMART goal-setting theory, where the criteria for the AHP are based on the SMART criteria (Shahin & Mahbod, 2007; Gözaçan & Lafci, 2020). Another possible combination of methods is the SMART goal-setting theory together with Fuzyy AHP, employed by Kaganski and Toompalu (2017) in their research on selecting KPIs. The Fuzzy AHP can also be used on its own (Ganguly & Rai, 2018).

The next method we will discuss is related to the Analytic Hierarchy Process, namely the Analytic Network Process (ANP). The ANP is a method used often to select KPIs (Rodrigues, Godina & Cruz, 2021). The ANP is a multi-criteria decision method that is considered a generalization of the AHP (Liu & Tsai, 2007). The ANP is deemed a valuable method for selecting KPIs, because the input of professionals is used to logically and consistently select KPIs (Carlucci, 2010).

This paragraph will discuss less frequently used KPI selection methods, which do have applications in decision-making problems. The first method is the DEMATEL method, which is most commonly used to produce a cause-and-effect diagram of the KPIs which are interdependent (Seker & Zavadskas, 2017). The DEMATEL can be used in combination with a literature review (Bapat, Sarkar & Gujar, 2022), as well as with expert opinions (Ansari, Kant & Shankar, 2020). A relatively new method to select KPIs is the Best Worst Method (BWM), which can be used in combination with a literature review (Moktadir et al., 2021). Another multi-criteria decision method is ELECTRE. Gonçalves, Dias, and Machado (2014) used ELECTRE as the main method to select KPIs in their research. The last method we will discuss in this review is Interpretive Structural Modeling (ISM), which was used by Amrina and Yulianto (2018) combined with a literature review and expert opinions.

Table A.6 in Appendix A shows an overview of KPI selection methods ordered by concepts. The first column shows the author(s) of the paper and the columns that follow show different concepts that this paper discusses. The last two columns describe the focus of the paper and the purpose with which the paper is written. To give an example, Dwivedi & Madaan (2020) discuss KPIs, literature review, and expert opinions in their paper. The focus lies on the expert opinion and the research is a case study.

Next, we have to decide which methods to employ during this research to identify and select relevant KPIs to display on the dashboard design. The first decision we make is to use a literature review and expert opinions to identify relevant KPIs for the dashboard, since these two methods are the most frequently used by other researchers to identify KPIs. Moreover, according to Snyder (2019) relating research to existing knowledge is the building block of academic research activities and according to Marr (2012) organization's preferences are the cause for distinctive relevant KPIs across organizations.

The second decision we make is to eliminate the less frequently used methods, due to the academic relevance of these methods. Frequently used and mentioned methods have built a reputation and relevance in research. Therefore we will choose between the frequently used methods Delphi technique, the ANP, the AHP, and the AHP combined with SMART goal-setting theory. To determine which method is most suitable for this research, the advantages and disadvantages that are commonly mentioned in research will be discussed.

AHP is a method for which no expert knowledge is needed, moreover, the creation of a hierarchical structure gives a clear and accurate insight into the problem (Kant & Gupta, 2022). On the other hand, Kant & Gupta (2022) also mention that the AHP deals with issues of consistency. The ANP is a suitable method to simplify complex problems (Ganguly & Rai, 2018). The method, however, relies heavily on experts' judgment (Liu & Tsai, 2007). The Delphi technique delivers concrete information, due to repeatedly tested answers (Linstone & Turoff, 1975). Nonetheless, according to Powell (2003) a weakness of the method is the lack of reliability and the lack of speed due to the reliance on expert response. The AHP together with SMART goal-setting theory allows for the definition of clear and measurable goals and accurately specified comparisons to be made (Shahin & Mahbod, 2007). A disadvantage of this method is the risk of the focus of the participants being too narrow, caused by the strict definition of SMART goals (Lawlor & Hornyak, 2012).

Since this research is limited to a timespan of 3 months, time-consuming methods do not have preference. Therefore, the Delphi technique will not be used. Moreover, there is a necessity for this research to be reliable, and the method can therefore not depend heavily on the experience of experts. The ANP will thus not be used as the method to select KPIs for the dashboard design. The AHP both separately from and together with the SMART goal-setting theory, therefore, appears to be the most suitable method. Due to the advantage of SMART goal-setting, the allowance for the definition of clear and measurable goals, we have chosen to adopt in this research the AHP together with SMART goal-setting theory to select relevant KPIs.

The AHP is developed by Saaty as a method for solving multiple criteria problems, which translates a problem into a hierarchical structure and carries out pairwise comparisons based on criteria (1988). The criteria in this case will be the SMART goal setting criteria. The SMART goal setting theory is composed of two concepts; the goal setting theory and the acronym SMART. The goal setting theory is about the motivation one gets when setting clear goals (Locke & Latham, 2013). The acronym SMART stands for 'Specific, Measurable, Achievable, Relevant, and Timely (Lawlor & Hornyak, 2012), and is used often in combination with goal setting theory (Day & Tosey, 2011). The AHP SMART goal setting approach is about comparing KPIs on the basis of SMART and the characteristics of the organization and its goals (Shahin & Mahbod, 2007). As was discussed, the AHP method deals with issues of consistency. To compensate for this issue, a consistency index was introduced which, if the value is sufficient, takes away the issue of consistency. In Section 4.1.4 'SMART Analytic Hierarchy Process', the method together with its execution are discussed.

3.2 KPI Visualization Choices

The previous section has explained several methods to identify and select KPIs. These KPIs are selected to be displayed on the dashboard. This dashboard displays visual representations of the KPIs with the use of Visual Analytics. Visual Analytics uses visual representations of data for analyzing purposes (Keim, Mansmann & Thomas, 2010). According to Marr (2012), visual representations are systems that specify data. The main goal of data visualization is to communicate information in a clear and effective way, and the choice of representation has an impact on the understanding and the interpretability of the data (Moore, 2017). The aim of this research is to create a dashboard design that improves the insight into the bottlenecks of the tape drive test process. The visual representations on the dashboard have to support the user to correctly interpret the information that is transferred. This literature review will discuss the criteria for choosing visual representations. Appendix C 'SLR KPI Visualization Choices' shows the approach for this Systematic Literature Review.

According to Zelazny (2001), choosing a suitable chart form is completely dependent on the message the information has to transfer. Zelazny argues that any of the messages derived from tabular data can be communicated via five kinds of comparisons:

- Component: percentage of a total.
- Item: ranking of items.
- Time series: changes over time.
- Frequency distribution: items within ranges.
- Correlation: relationship between variables.

Stoltzman (2018) recommends to focus on the aims of the visual representation when selecting a visual representation. Stoltzman mentions the following purposes for data visualization:

- Comparison.

- Relationship.
- Distribution.
- Trend.
- Composition.

Lebanon and El-Geish (2018) discuss in their research thirteen types of plots that can be used for KPI visualization. The first one, a scatter plot, is a visualization that allows to visualize two numerical variables along two axes. A box plot visualizes the range, minimum, maximum, and median values of a data set . The line plot is the third display they discuss, which shows information as a series of data points connected by a straight line. A variation of the line plot are time series, where the horizontal axes is interpreted as time. Another variation of the line plot is the area plot, where the area covered under the line plot is important. A bar chart shows categorical data, data that can be identified based on names given to them, with rectangular bars. A column chart shows multiple rectangular bars for different attributes. A histogram splits data into bins, and then plots the frequency of the data points in the bins. Pie charts use slices to show proportions and percentages between categories. Similar to the pie chart is the donut chart, with as only difference a hole in the middle of the circle to emphasize the length of the arcs. Gauge charts show the minimum, maximum, and current values of the data and examples of Gauge charts are the Speedometer and the Ranking meter. A density plot is similar to a histogram, but instead of bins, it has a smooth curve through the top. A heat map shows correlations between different features in a data set with colors, and lastly pair plots are utilized to plot all possible scatter plots for each pair of variables. All these visualizations are shown in figures displayed in the second column of Table 4.

Lebanon and El-Geish (2018) give an explanation of the different visual representations. However, for this research, criteria have to be set for choosing visual representations for KPIs. As mentioned before, Stoltzman (2018) urges to focus on the aims of a visual representation when determining a representation. The author assigns different media displays to the earlier mentioned aims of visualization:

- Comparison: Area plot, Bar chart, Bullet chart, Column chart, Line plot, or Scatter plot.
- Relationship: Line plot or Scatter plot.
- Distribution: Bar chart, Box plot, or Column chart.
- Trend: Column chart or Line plot.
- Composition: Donut chart, Pie chart, Stacked bar chart, or Stacked column chart.

Zelazny (2001) argues that one of the five basic chart forms can be used for any comparison: the pie chart, the bar chart, the column chart, the line chart, and the dot chart as shown in Figure 9.

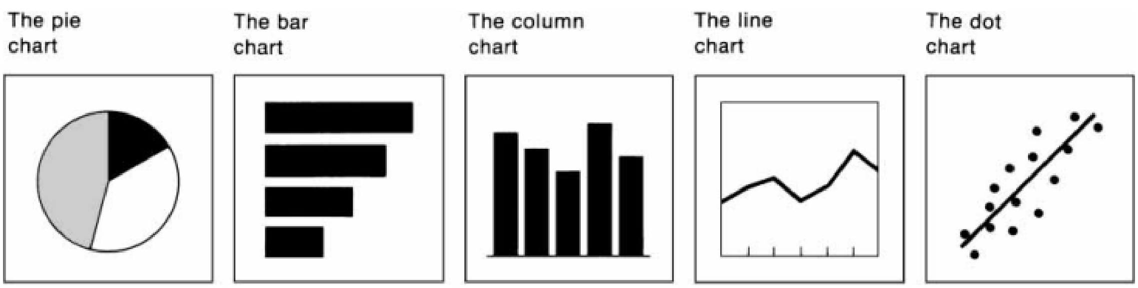


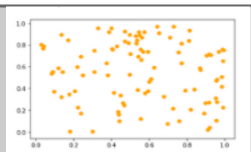
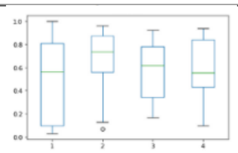
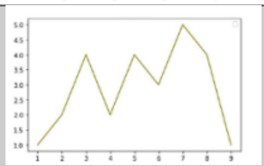
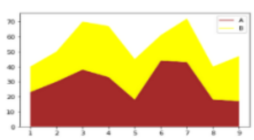
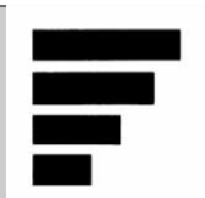
Figure 9 Five different chart types (Zelazny, 2001)

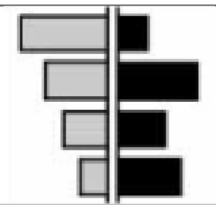
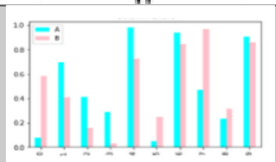
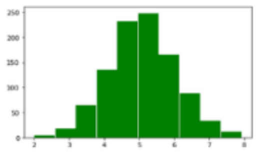
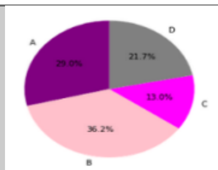
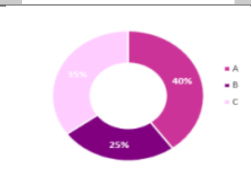
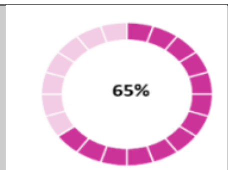
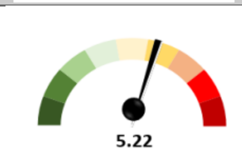
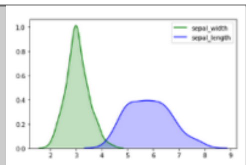
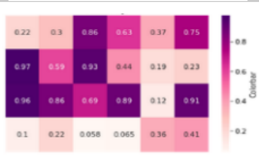
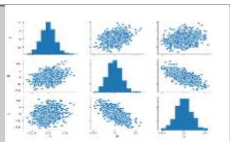
According to the author, a component comparison can best be visualized using a pie chart, an item comparison by a bar chart, a time series comparison with a column chart or line chart, the frequency distribution by a histogram (variation of column chart), and a correlation comparison by a dot chart or a paired bar chart.

Next to a classification of visualizations per aims, Stoltzman (2018) also classifies visualizations as good, bad or ugly. A good visualization clearly communicates a message, is customized to the appropriate audience, and is customized to the presentation medium. Moreover, a good visualization is memorable to the viewers and makes an impact on the understanding of the subject matter. A bad visualization is hard to interpret, is unintendedly misleading, and contains unnecessary information. An ugly visualization is almost impossible to interpret, consists of redundant information and is intendedly created for misleading the audience.

We have also looked at other theories about visual representations, such as the theories from Shneidermann (1996); the information visualization seeking mantra 'Overview first, zoom and filter, then details-on-demand' and the seven data types he distinguishes. We have, however, chosen to not use these theories and instead only focus on the theories from Lebanon and El Geish (2018), Zelazny (2001), and Stoltzman (2018), because they directly show relations between visual representations and the message they send. Another relevant research by Halim & Tufail (2017) proposes a metrics for visualizations based on effectiveness, expressiveness, readability, and interactivity to evaluate whether the chosen visualization is suitable. This evaluation of the suitability of the chosen representations does not fit in the scope of this research, but is a very interesting direction for future research. Table 4 shows the discussed visual representations together with the criteria for choosing this representation.

Table 4 KPI Visualizations

Visual representation	Example	Criteria
Scatter plot		Comparison, Relationship
Box plot		Distribution
Line plot		Time series (comparison), Frequency (comparison), Comparison
Area plot		Comparison
Bar chart		Item (comparison), Correlation (comparison), Comparison, Distribution

Stacked bar chart		Correlation (comparison)
Column chart		Time series (comparison), Frequency (comparison), Comparison, Trend
Histogram		Frequency (comparison), Distribution
Pie chart		Component (comparison), Composition
Donut chart		Composition
Speedometer		Comparison
Ranking meter		Comparison
Density plot		Frequency (comparison)
Heatmap		Correlation (comparison)
Pair plots		Comparison

Chapter 4 KPI selection and visualization

After we have gained more knowledge on KPI selection and visualization, we can use these methods to select KPIs and suitable visualizations for these KPIs. This chapter discusses the utilization and the outcomes of these methods. Section 4.1 'KPI Selection' discusses the KPI selection method and the outcome of this method in terms of KPIs to be displayed on the dashboard. Next, in Section 4.2 'KPI Measuring', we describe how the KPIs can be measured within the current BI platform of Bluetron. Lastly, Section 4.3 'KPI Visualizations' shows the visualizations we have chosen for the selected KPIs.

4.1 KPI Selection

The goal of this research is to develop a dashboard design that creates insight into the bottlenecks of the tape drive test process. On this dashboard a number of KPIs need to be shown, and the literature tells that the optimal number is fewer than 20 (Kaplan & Norton, 1997). Parmenter (2019) suggests that about 10 KPIs on a dashboard is sufficient, and Hope and Fraser (2004) even indicate fewer than 10 as an appropriate number of KPIs. Based on the systematic literature review performed in Section 3.1 'KPI Selection Method', the Analytic Hierarchy Process has been deployed for the purpose of selecting KPIs. The input for the AHP is KPIs, and therefore we first have to identify KPIs through a literature study and through gathering expert opinions. The KPIs that are already available at Bluetron, discussed in Section 2.2 'Available KPIs', are also considered as input for the Analytic Hierarchy Process. The identification of KPIs is discussed in Sections 4.1.1 'KPIs in Literature', 4.1.2 'Expert Opinion KPIs', and 4.1.3 'Company KPIs'. The selection of KPIs with the Analytic Hierarchy Process is discussed in Section 4.1.4 'SMART Analytic Hierarchy Process'.

4.1.1 KPIs in Literature

The aim of this literature study is to identify KPIs specific to the sector Bluetron is active in. The main sector for the tape drive test process is the testing industry. However, as Bluetron outsources the actual repair of the tape drives, only the KPIs concerning testing are relevant. The KPIs about the repair of products can be ignored. As Bluetron outsources services to another company, outsourcing KPIs are also relevant for Bluetron. Moreover, the overarching sector Bluetron is active in is the remanufacturing sector. Therefore, a literature review will be performed to identify KPIs in the fields of testing, outsourcing, and remanufacturing.

Bluetron tests tape drives to determine whether or not they are defective. In his book, Sarialioglu (2014) has described metrics and KPIs for a testing environment. He mentions total test effort, which is the effort that goes into one test which can for example be expressed in time. He also mentions total number of defects, a KPI that is available at Bluetron already as 'NDF Fail'. Sarialioglu (2014) mentions the defect rejection rate, a KPI that already exists at Bluetron as 'NDF Pass'. The author also mentions KPIs about the repair of products which we do not take into account, because Bluetron does not repair the tape drives itself. The following KPIs result from the literature study on KPIs in the test industry:

- Total Test Effort
- Total Number of Defects (NDF Fail)
- Defect Rejection Rate (NDF Pass).

Bluetron outsources the repairing activities of the tape drives to Partner Y. Ahmed (2019) has performed research on KPIs in the outsourcing business and the following list mentions the most relevant KPIs for this research:

- On-time delivery
- Reliability
- Accuracy
- Increased productivity

On-time delivery is about the number of deliveries that occurred according to the agreement of the two parties, in this case Bluetron and Partner Y. Reliability in this case refers to the reliability of Partner Y, which can be defined as the on-time deliveries as a fraction of the total number of deliveries to Bluetron. Accuracy in this case refers to the accuracy of Partner Y, which can be calculated as the number of drives that are successfully repaired by Partner Y divided by the total number drives returned from Partner Y. Lastly, increased productivity is mentioned by Ahmed (2019) in his research, which refers to the increase in productivity because of the choice to outsource an activity.

Graham et al. (2015) have performed research on performance measurement and KPIs for the remanufacturing industry. They summarize relevant KPIs in different categories. For this research, the most suitable category is 'process'. Since we are looking to determine bottlenecks in the tape drive test process, we have focused on this category. The first KPI they mention is throughput time, which is the time between initiation and delivery of a product. Another KPI is Work in Progress (WIP), which Graham et al. (2015) describe as partly finished goods that wait to be completed. Lastly, the core disposal rate is discussed in the paper, which translates at Bluetron into the scrap tape drives. The following list shows the KPIs relevant for the remanufacturing industry in the category 'process':

- Throughput time
- Work in Progress
- Core disposal Rate

4.1.2 Expert Opinion KPIs

In the previous section, we performed a literature review on relevant KPIs for Bluetron. In this section we focus on expert opinions about KPIs. In this case, the experts are the four employees at Bluetron who have also filled in the start evaluation survey. These four employees have different functions within the process and therefore we expected to gather KPIs from multiple perspectives, such as operational and strategic KPIs. We performed semi-structured interviews with these employees for which the goal was to discover KPIs which the employees value as relevant. Semi-structured interviews allow for clear guidance throughout the interview as well as open-ended responses for more in-depth information (Bolderston, 2012). Because we wanted a list of relevant KPIs with additional information or explanation about the KPIs, we deemed semi-structured interviews suitable. During the interviews, we first presented the KPIs resulting from the literature search to gather the opinions about the relevance of these KPIs. The employees were also asked to propose KPIs that were not yet presented, but which they found relevant for the tape drive test process.

Table 5 shows the result of the four interviews, namely the KPIs from the literature which the employees found relevant and KPIs proposed by the employees themselves. The first column displays the KPIs, the second column displays the origin of the KPIs and column three displays the definition of these KPIs.

Table 5 Expert Opinion KPIs with definition

KPI	Origin	Definition
Total number of defects (NDF Fail)	BI platform Bluetron and Literature	The number of tape drives per unit of time which fail the NDF test.
Defect rejection rate (NDF Pass)	BI platform Bluetron and Literature	The number of tape drives per unit of time which pass the NDF test.
WIP Partner Y	Literature	The Work-In-Progress at Partner Y, or in other words the total number of drives present at Partner Y.
WIP Bluetron	Literature	The Work-In-Progress at Bluetron, or in other words the total number of drives present at Bluetron.
Total WIP	Literature	The total Work-In-Progress, meaning the Work-In-Progress at Bluetron plus the Work-In-Progress at Partner Y.
Number of brackets at Bluetron	Expert opinion	The total number of brackets (in this case a single bracket, the brackets attached to the bricks do not belong to this KPI).
Productivity per engineer	Expert opinion	The total number of tape drives tested per engineer per week.
Throughput time Bluetron	Literature	The total time a tape drive spends in the process at Bluetron.
Throughput time Partner Y	Literature	The total time a tape drive spends in the process at Partner Y.
Number of complaints	Expert opinion	Total number of complaints received from Customer X.
Working stock	Expert opinion	Total amount of work in hours that can still be executed by Bluetron with the current stock.
Reliability Partner Y	Literature	The on-time deliveries by Partner Y as a fraction of the total number of deliveries to Bluetron.
Accuracy Partner Y	Literature	the number of drives that are successfully repaired by Partner Y divided by the total number drives returned from Partner Y.

It can be concluded from Table 5 that the four employees found the KPIs 'Total Test Effort', 'On-time delivery', 'Increased productivity', and 'Core disposal rate' that we identified in the literature irrelevant. We will thus not use these KPIs as input for the SMART Analytic Hierarchy Process. The KPIs in Table 5 will be used as input for the SMART Analytic Hierarchy Process.

4.1.3 Company KPIs

As was discussed in Section 2.2 'Available KPIs', Bluetron already has access to a number of KPIs about the performance of the tape drive test process. The list below shows these KPIs, for which the definitions can be found in Section 2.2 'Available KPIs'. These KPIs will also act as input for the SMART Analytic Hierarchy Process.

- NDF fail
- NDF pass
- Booked External
- Packed

- No NDF
- Test by fail reason
- NDF pass/fail per article
- NDF pass/fail by customer
- Warranty parts received
- Warranty parts accepted
- %warranty
- DOA
- %DOA
- Throughput time between Pick and NDF
- Throughput time between NDF and Extern
- Throughput time between Pick and Packing

4.1.4 SMART Analytic Hierarchy Process

The AHP method has been deployed during a focus group with 4 employees involved with the tape drive test process. The focus of this section will primarily be on the outcome of the method. Table 6 shows this outcome. The method is explained in detail in Appendix D 'SMART Analytic Hierarchy Process'.

By analyzing three definitions about bottlenecks, we conclude that a dashboard consists of three aspects: a dashboard is a visual object, it shows the most important information, and they have been created for a certain goal (Few, 2006; Vilarinho, Lopes & Sousa, 2017; Pauwels et al., 2009). The visual objects are created through visual representations of the selected KPIs. The most important information in this case is the KPIs, that are selected with the focus group. The goal for the dashboard has already been determined at the beginning of this thesis, namely to create insight into the bottlenecks of the test process. This vision for the dashboard was clearly communicated at the beginning of the focus group to make sure that the KPIs were selected with the correct vision in mind. Moreover, to make sure that the term 'bottleneck' is correctly understood, we stated the following definition: 'The workstation with the maximum processing requirement' (Appelbaum et al., 2012).

The next step of the focus group was to fill in the scores of the KPIs for the SMART criteria as proposed by Shahin and Mahbod (2007), after which the employees filled in the pairwise comparison matrix. We calculated the final scores for the KPIs which are shown in Table 6. The 21 input KPIs are shown in the first column and the origin of the KPIs are shown in the second column. The individual scores for the SMART criteria, which are explained in Appendix D, are shown in columns 3 until 7, and the final score is shown in column 8. As was discussed earlier in this chapter, the number of KPIs on a dashboard should unanimously be less than 20 (Kaplan & Norton, 1997). Other papers suggest to limit the number of KPIs on a dashboard to around 10 (Parmenter, 2019; Hope & Fraser, 2004). We will therefore make an attempt to select around 10 KPIs and a suitable cut-off score has to be determined. If we utilize a cut-off score of 4.0, only 2 KPIs are selected. A cut-off score of 3.5 yields 8 KPIs, and a cut-off score of 3.0 yields 11 KPIs. As the literature suggests, the number of KPIs should be around 10. As we would like to portray more than 2 KPIs on the dashboard, we will utilize the cut-off score 3.5. The green rows in Table 6 display the selected KPIs for the dashboard for Bluetron.

Table 6 KPI Final Scores where green rows represent the selected KPIs and grey rows represent the KPIs that are not selected during the focus group

KPI	Origin	S	M	A	R	T	Score
NDF Fail	BI platform and Literature	3	5	4	4	4	3.73
NDF Pass	BI platform and Literature	3	5	4	5	4	3.83
Booked External	BI platform	3	5	5	3	5	4.09
Packed	BI platform	3	5	5	2	4	3.75
No NDF	BI platform	1	4	1	1	2	1.51
Work in Progress Partner Y	Literature	3	3	3	1	3	2.80
Work in Progress Bluetron	Literature	3	4	4	2	3	3.21
Brackets present at Bluetron	Expert opinion	2	5	2	1	3	2.41
NDF Pass/Fail per article	BI platform	1	5	3	4	3	2.56
Number of complaints	Expert opinion	4	4	4	5	3	3.86
Working Stock	Expert opinion	2	3	3	1	4	2.68
Warranty parts received	BI platform	1	4	2	3	2	1.92
Warranty parts accepted	BI platform	1	3	2	3	2	1.83
%Warranty	BI platform	2	4	2	4	2	2.38
%Dead on Arrival	BI platform	2	4	2	5	3	2.71
Total Work in Progress	Literature	4	3	4	2	4	3.71
Productivity per Employee	Expert opinion	2	2	5	1	5	3.26
Reliability Partner Y	Literature	2	2	1	4	2	1.98
Accuracy Partner Y	Literature	1	2	1	3	3	1.76
Throughput Time Bluetron	Literature	5	4	4	3	4	4.26
Throughput time Partner Y	Literature	4	2	3	3	5	3.74

After the KPIs had been selected during the focus group, we evaluated the KPIs on their suitability together with the employees at Bluetron. The following decisions were made based on this evaluation:

- As the total Work-In-Progress consists of the Work-In-Progress at Bluetron and the Work-In-Progress at Partner Y, it was decided that this composition is also of importance to the employees at Bluetron. Therefore, the total Work-In-Progress will be expressed as the addition of Work-In-Progress Bluetron and Work-In-Progress Partner Y.
- After a discussion on the KPI Throughput Time Bluetron, it became apparent that the employees would benefit most from this KPI if it is divided into 5 stages. These 5 stages are based on the movement of the tape drives to a different department within Bluetron. This way, if the throughput time is for example extraordinarily high in one of the 5 stages, one department is responsible for this increase in throughput time. The following 5 stages have been determined:
    - Upload to Pick

- Pick to Extern
- Pick to Packed
- Extern to Brick Pick
- Receive to GOO.

4.2 KPI Measuring

This section will discuss the measurements of the KPIs and in particular whether the KPIs are measured already. As in the research of Vilarinho, Lopes and Sousa (2018) on developing and implementing dashboards in SMEs (Small and Medium Enterprises), we have also analyzed the records that are filled in by operations employees. We have established a relationship between the current records and the necessary records for the KPIs to be displayed on the dashboard. By doing this, we have determined vital records that should be made during the process to make Bluetron's information system more complete.

We performed a semi-structured interview with one employee who is involved with the tape drive test process. This employee has experience with the BI platform that Bluetron uses and already works with a report that was specifically designed for the tape drive test process. Most of the employees that are involved with the tape drive test process know of the existence of this report. From semi-structured interviews with these employees, it has become apparent that they feel that the report is too complicated for them. They are not able to correctly convert the available data into useful information. During the interview about KPI measuring, we discovered that most of the KPIs are already calculated, or can be extracted from the available data. The dashboard will thus not show much new data, but will make the data interpretable for the employees. This way, useful information can be retrieved from the screen.

The analysis on data gathering at Bluetron has resulted in one additional record that has to be made, namely for the KPI that displays the throughput time between receiving the tape drive from Partner Y and the tape drive receiving the GOO status. GOO is short for 'good', which means that the drive is officially repaired. The following list shows the KPIs that will be shown on the dashboard together with the measurements.

- NDF Pass and NDF Fail
  NDF Pass and NDF Fail are KPIs that are already calculated and shown in the BI platform. The two KPIs are currently visualized in a bar chart as percentages. Since the two KPIs describe the number of tape drives that did or did not pass the NDF test, the two percentages have to add up to 100%. As the KPIs are already calculated, we will not go into the measuring of these KPIs.
- Extern
  Extern is an example of a KPI that has not yet been calculated, but can be extracted from the available data at Bluetron. To calculate this KPI, we have to make use of the status of the tape drives. During the process, tape drives receive a certain status based on the part of the process they are located in. The KPI Extern is a KPI that shows a list of individual tape drives that hold the status 'extern' for longer than 14 days. Tape drives with the status 'extern' have failed the NDF test and will thus be shipped to Partner Y to be repaired. During the focus group on KPI selection, it has been determined that the department can take at most 14 days to ship the tape drive to Partner Y after it has received the status 'extern'. When the tape drive holds the status 'extern' for longer than 14 days, the process is failing and attention is needed. This KPI can be determined by daily updating the number of days a tape

drive holds the status 'extern', and only displaying the tape drives for which the number of days exceed 14.

- Packed

  To calculate the KPI Packed, the same procedure as for the KPI Extern has to be executed. This KPI is again based on the status of a tape drive, in this case the status 'packed'. When a tape drive holds the status 'packed', it means that the tape drive is repaired and ready to be shipped to Customer X. During the focus group on KPI selection, it has been determined that the department can again take at most 14 days to ship the pack the tape drive to go to Customer X. The KPI can thus be determined by daily updating the number of days a tape drive holds the status 'packed', and will only show the tape drives for which the number of days exceed 14.
- Work-In-Progress

  During the focus group on KPI selection it became apparent that Total Work-In-Progress should be displayed on the dashboard. The Work-In-Progress at Partner Y can be derived from the available data by adding two columns from the tape drive test report, namely 'OOW (bestel)' and 'Warr (bestel)', where 'OOW' means 'Out of Warranty', 'Warr' means 'Warranty', and 'bestel' means 'order'. The total Work-In-Progress is already a KPI under a different name in the BI platform of Bluetron, namely 'Open Verkoop'. 'Open Verkoop' is a number stating how many drives still need to be returned to Customer X, and thus the total number of tape drives that is currently present in either the process of Bluetron or in the process of Partner Y. The Work-In-Progress Bluetron is not yet calculated, but can be derived from subtracting the KPI Work-In-Progress Partner Y from the KPI Total Work-In-Progress. This way, no new data has to be generated to communicate the Work-In-Progress KPIs on the dashboard for Bluetron.
- Number of complaints

  The number of complaints received from Customer X per unit of time is not yet calculated at Bluetron. However, it became known that there exists a function in the ERP system of Bluetron, called '8D Analysis'. Here, employees can file the complaints given by Customer X. The total number of complaints per unit of time can thus be derived from the total number of times the 8D Analysis is used.
- Throughput time Bluetron

  The throughput time at Bluetron has been chosen to be displayed on the dashboard. The following list shows the 5 stages together with the measurements:

1. Throughput time between the upload of the tape drive and the movement of the drive to the production floor.

   This throughput time is already calculated in the BI platform under the name 'upload tot pick'.
2. Throughput time between the movement of the tape drive to the production floor and the booking external of this tape drive in case of a failed NDF or library test;

   This throughput time is also already calculated in number of days under the name 'pick tot extern'.
3. Throughput time between the movement of the tape drive to the production floor and the packing of the tape drives in case of a passed NDF and library test

   This throughput time is not yet calculated. The information can, however, be derived from two dates in the BI platform that are tracked: 'Receive shipment production' and 'extraction customer order'. If the system counts the difference in days between these two activities, the targeted throughput time is calculated.
4. Throughput time between booking the drive external and shipping the drive to Partner Y

This throughput time is already calculated in number of days under the name 'extern tot brick pick'.

5. Throughput time between receiving the tape drive from Partner Y and the tape drive receiving the GOO status (which means it is repaired)
This KPI is the only KPI for which extra data has to be generated and a new step in the process has to be added. When tape drives are shipped to Partner Y, they lose their unique identity, namely the repair number. When the drives return to Bluetron, the only information known about the tape drive is the purchase order number and the batch number. This batch number is based on the day of arrival at Bluetron. At the moment, this batch number is not tracked by Bluetron and only the purchase order number is known of a tape drive. This purchase order number, however, does not contain any information about the day of arrival at Bluetron. Therefore, Bluetron will have to add a step in the process where the batch number of returned tape drives is tracked by a sticker such that the day of arrival is known. Figure 10 shows the BPMN model of Stage 5 Checking in which this step is added to the process. The added step is visualized with a green square. When this is done, the throughput time can be calculated by counting the difference in days between the day of arrival at Bluetron (tracked by the batch number) and the day the tape drive receives the GOO status. This is the last of the 5 stages and after this stage, the tape drive is shipped to Customer X.

- Throughput time Partner Y
The throughput time of Partner Y is a KPI that has not yet been calculated, but can be derived from the available data. The difference in days between the creation of the purchase order of the shipment that has to go to Partner Y and the moment this purchase order is stated as 'received' by Bluetron can be seen as the throughput time of Partner Y. Therefore, if this difference is shown as a new KPI, the throughput time of Partner Y becomes transparent.

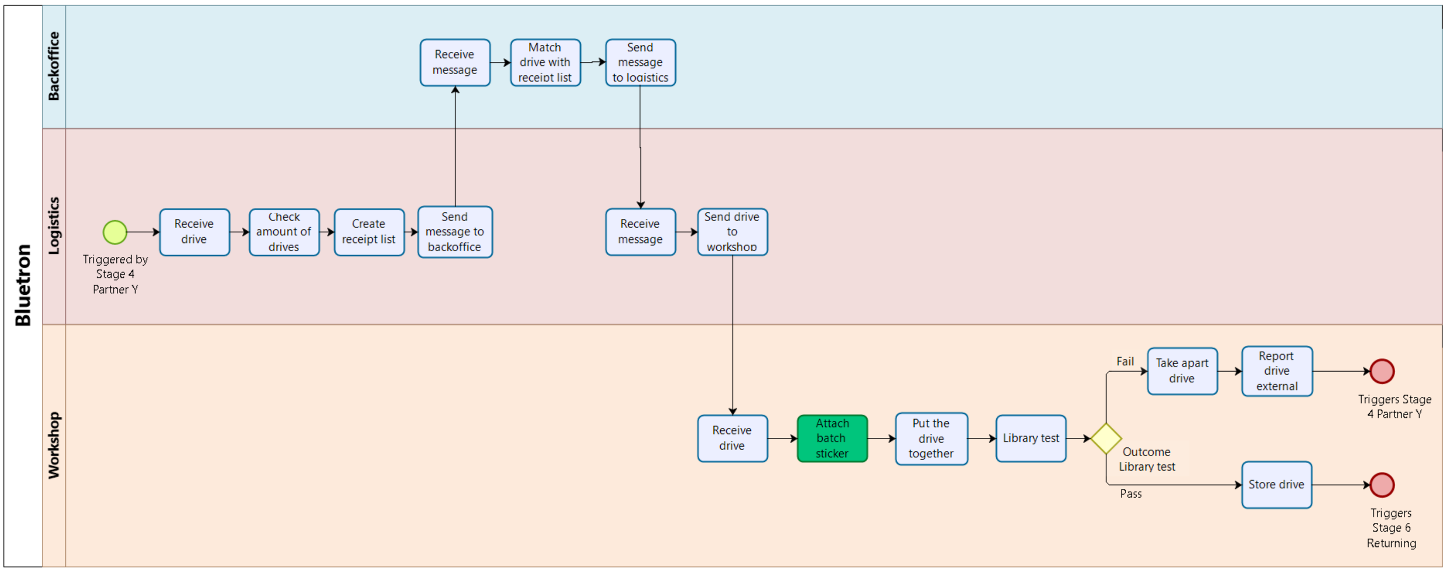


Figure 10 BPMN model of Stage 5 Checking with the added step in the green square

4.3 KPI Visualization

The KPIs discussed before have to be displayed on the dashboard with suitable. This section will use the information gathered in Section 3.2 ‘KPI Visualization Choices’ to choose suitable visualizations for the KPIs to be displayed on the dashboard for Bluetron.

During the focus group, we determined that the values of the KPIs NDF Fail and NDF Pass have to stay in between predetermined benchmark values. In the case that the KPIs have a value outside the benchmark values, the dashboard should have the functionality to visually alarm the users. We want to compare the real value of the KPIs to the benchmark values. A ranking meter shows the minimum, maximum and current value of data (Lebanon & El-Geish, 2018), and according to Table 4 is suitable for comparison. We therefore choose to use the ranking meter for the KPIs NDF Fail and NDF Pass. The minimum and maximum values will display the benchmark values and the current value will be the actual value of the KPI. The benchmark values for the KPI NDF Pass are 15% and 24%, which means the system should alarm the users when the value of the KPI is outside these values. The benchmark values for the KPI NDF Fail consequently are 76% and 85% and the system should alarm the users when the value lies outside these values. Figure 11 shows the situation when the value of the KPI is outside the benchmark values and Figure 12 shows the situation when the value of the KPI is inside the benchmark values.

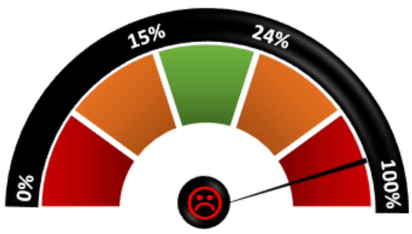


Figure 11 NDF Fail and Pass visualization outside benchmark values

Figure 12 NDF Fail and Pass visualization inside benchmark values

The KPIs Extern and Packed show the tape drives that hold the status ‘extern’ or ‘packed’ for longer than 14 days. When this occurs, the tape drive will appear in a table showing the article number of this tape drive together with the total number of days the status is held. Because it is of importance that the data is arranged into columns and rows, we have chosen a table as visual representation. Figure 13 shows an example of how this table will look when the tape drives ‘128794’, 346098’, and ‘124583’ have held the status ‘extern’ or ‘packed’ longer than 14 days. In the dashboard, the KPIs Extern and Packed both have their own table.

Article number	Days
128794	18
346098	15
124583	15

Figure 13 Extern and Packed visualization

The KPI ‘Number of Complaints’ will show the number of received complaints from the customer per unit of time. Since this data is a single measure, it can simply be visualized with a number (Evergreen, 2019). The number will, when it exceeds the benchmark value, turn red to show that the limit has been exceeded. This benchmark value has been determined during the brainstorm and is set at 3, where 3 is the first value that is considered too high. Figure 14 shows the visualization when the number of complaints is below the benchmark value and Figure 15 shows the visualization when the number of complaints is above the benchmark value.

2

Figure 14 Complaints visualization below benchmark value

4

Figure 15 Complaints visualization above benchmark value

‘Total Work-In-Progress’ resulted as one of the KPIs to be displayed on the dashboard. As was discussed in Section 4.1 ‘KPI Selection’, this KPI will be shown as a composition of Work-In-Progress at Bluetron and Work-In-Progress at Partner Y. The emphasis will be on the total number of tape drives in the process and the ratio between tape drives present at Bluetron and tape drives present at Partner Y. As this ratio can be seen as an item comparison, Table 4 shows that a bar chart is the most suitable visualization for this KPI. This bar chart will contain three bars; one for the work in progress at Bluetron, one for the work in progress at Partner Y, and one for the total work in progress. Figure 16 shows this visualization.

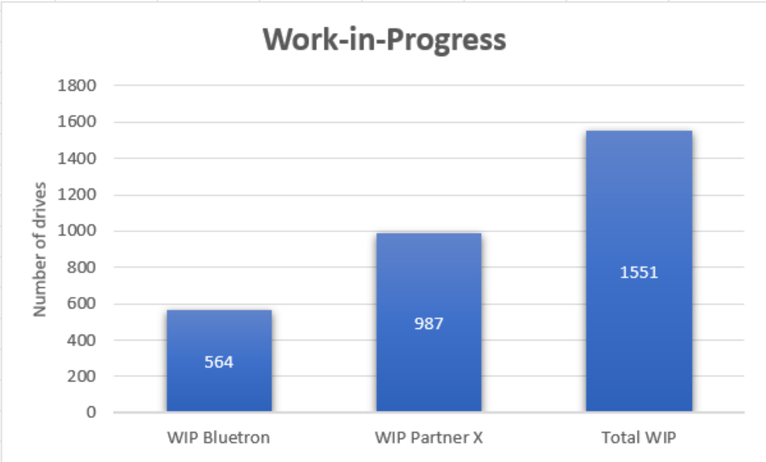


Figure 16 Work-in-Progress Visualization

Moreover, the total throughput time will also be visualized. Together with the employees at Bluetron, we have determined that we want to compare the throughput times over time visualized per month. Therefore, as Table 4 suggests, a line chart will be used for this time series comparison with the months on the horizontal axes and the number of days on the vertical axes. Figure 17 shows this visualization.

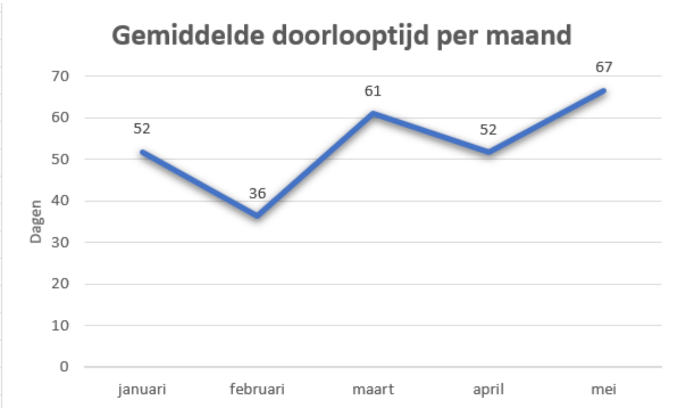


Figure 17 Throughput Time Visualization

Chapter 5 Dashboard design

Now that the KPIs for the dashboard have been selected and suitable KPI visualizations have been chosen, we focus on the design of the dashboard. In this chapter, the aim is to gain knowledge about dashboard designs and thereafter create a dashboard design. Section 5.1 'Literature Dashboard Design' discusses the Systematic Literature Review we performed about dashboard designs and Section 5.2 'Dashboard Design' shows and explains the dashboard design we created based on the Systematic Literature Review.

5.1 Literature Dashboard Design

Multiple researchers have attempted to create a definition of a dashboard, which has resulted in a variety of definitions. Few (2006) defines a dashboard to be 'a visual display of the most important information needed to achieve one or more objectives', whereas Vilarinho, Lopes and Sousa (2017) characterize a dashboard to be a visual and interactive performance management tool that displays the most important information in order to achieve goals across an organization. Pauwels et al. (2009) describe a dashboard as 'a relatively small collection of interconnected key performance metrics and underlying performance drivers that reflects both short- and long-term interests to be viewed in common throughout the organization'. These researchers have all created a different definition. However, these definitions share similarities; dashboards are visual objects, they display the most important information, and they have been created for a certain goal or objective. In Chapter 1 'Introduction', we have already defined the objective for the dashboard, namely to create insight into the bottlenecks of the tape drive test process. In Section 4.1 'KPI Selection' we have determined the most important information, in this case key performance indicators concerning the tape drive test process. And lastly, the visual displays have been chosen in Section 4.3 'KPI Visualizations'. In this chapter, we will design the dashboard according to the rules and findings stated in the literature on dashboards. Appendix E 'SLR Dashboard Design Guidelines' shows the approach for this Systematic Literature Review.

Dashboards should enable the user to access and quickly evaluate multiple aspects of the performance of the company (Yigitbasioglu & Velcu, 2012). According to Few (2006), a dashboard should therefore fit on a single screen to display the information needed to achieve the set objectives. The objectives in this case are 'effectiveness', 'efficiency', and 'the ability of the dashboard to locate bottlenecks', as explained in Section 1.2.6 'Problem Quantification'. Pastushenko, Hynek and Hruska (2019) argue that dashboards represent the presentation layer and they serve the purpose of communication. Dashboards have to be customized (Few, 2006), which is a characteristic we have attempted to realize by taking into account the characteristic of test processes and the opinions of the employees at Bluetron. This way, the dashboard is customized for test processes and in particular the tape drive test process at Bluetron.

Few (2006) describes three types of dashboards: strategic, analytic, and operational dashboards. Strategic dashboards focus on high-level performance, whereas analytic dashboards encourage more interaction with the data to enable the user to examine the causes of a certain value or failure. Operational dashboards on the other hand are used to monitor and safeguard operations and these dashboards have to be very dynamic and immediate. As the goal of this thesis is to design a dashboard that supports locating bottlenecks, and thus examining causes of low performance, we will design an analytic dashboard.

We have discussed the definition and characteristics of dashboards so far. Pastushenko, Hynek, and Hruska (2019) discuss that aesthetics and the first impression of users play a vital role in the usability of the dashboard. This suggests that the design of the dashboard is also an essential part of creating a dashboard. Yigitbasioglu and Velcu (2012) distinguish in their literature review on dashboards between two types of design features: functional features and visual features. Functional features are indirectly related to visualization: they describe what the dashboard can do, such as drill-down functions or selection criteria. Visual features refer to the principles of visualizing data, in other words how effectively the data is displayed to the end user. With 'effectively', we mean the ability of the end user to perceive the maximum amount of information in a minimal amount of time.

We will first get into the functional features for dashboards and later discuss visual features. Dinmohammad and Wilson (2021) have performed a study on data analytics and visualization and found that one of the most important requirements for end-users is 'interactivity'. Interactivity in a dashboard aims to customize the dashboard according to the needs of the user (Zhou et al., 2022), and supports exploration and interrogation of the presented data (Sharma et al., 2023). Interactive dashboards recognize that static dashboards offer low human involvement, while interactive dashboards invite users to be highly involved with the contents on the dashboard (Meignan et al., 2015). Eckerson (2005) suggests that individuals should be able to drill down, filter information, or are automatically alerted to business situations. Yigitbasioglu and Velcu (2012) emphasize in their research on dashboards that the drill down feature is a critical component. A dashboard without the drill down feature might pressure an employee with high analytical skills to work with aggregate data that is insufficient when the employee is looking for small details. Therefore the drill-down feature should in most cases be implemented.

As was already explained, visual features of a dashboard refer to the effectiveness of the data display to the end user (Yigitbasioglu & Velcu, 2012), where 'effectiveness' means that the maximum amount of information is perceived in a minimal amount of time. Few (2006) also elaborates on this subject and mentions that the non-data pixels, which are any pixels that do not display data, should be kept minimal. Bach et al. (2022) have performed an extensive review on dashboard design patterns through an extensive survey of 83 dashboards. They came across a pattern of tradeoffs that have to be made when visually designing a dashboard. Figure 18 shows these tradeoffs. The main lessons which are relevant for this research are that a degree of abstraction is needed in order to limit the number of pages and if you decrease the number of pages (e.g. to 1), the interaction with the dashboard is increased by for example using the drill-down features mentioned above.

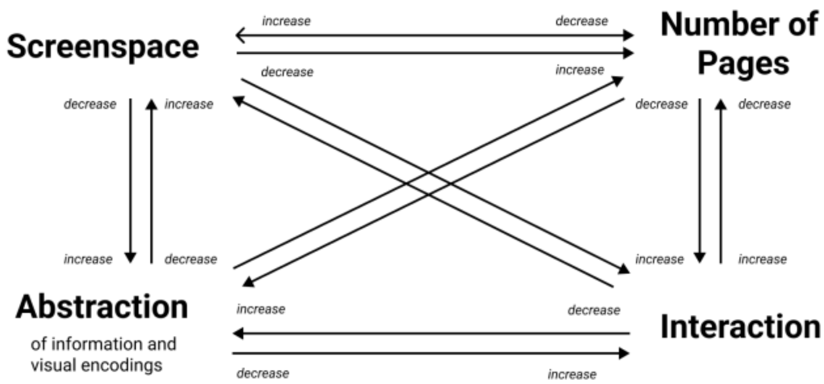


Figure 18 Design Tradeoffs in Dashboard Design (Bach et al., 2022)

The task of portraying a lot of data on a single screen while keeping the interpretability as high as possible can be challenging.The following section shows the common mistakes that Few (2006) mentions to ensure that we avoid making these mistakes during our research.

- Surpassing the borders of a single screen
- Providing insufficient context for the data
- Portraying exaggerated amounts of detail
- Utilizing a big variety in media displays
- Incorrectly encoding quantitative data
- Poorly arranging media displays on the dashboard
- Ineffectively highlighting important data
- Using decoration on the dashboard that has no meaning
- Mis- or overusing color

The information stated in this section is used when designing the dashboard for Bluetron.

5.2 Design

The purpose of this section is to explain how we have combined KPI visualizations in a dashboard design. We will first discuss the visual features of the dashboard and we will thereafter discuss the functional features.

According to Few (2006), a dashboard should fit in one screen. In the case of this research the screen of a laptop or computer, because those are the devices Bluetron mostly operates with. Moreover, Bach (2022) argues that a decrease in the number of pages of a dashboard equals an increase in interaction, one of the most important requirements for end-users (Dinmohammad & Wilson, 2021). We have therefore decided that the dashboard consists of one page. The position of the KPIs on this single screen dashboard is based on the theory provided by Few (2006), namely that the most important KPI should be placed in the top left corner, since that is generally the first place users look when they open a dashboard. During the focus group on KPI selection, we determined that the most important KPIs are NDF Fail and NDF Pass, because these KPIs determine the distribution of drives over the different parts of the process. NDF Fail and NDF Pass are therefore placed in the top left corner. Few (2006) also mentioned that KPIs that are placed near each other are most often compared with each other. For that reason, we have placed the 6 graphs about throughput times in the same section, such that the performance of different departments within Bluetron can be easily compared. The same holds for the KPIs Extern and Packed.

Meaningless decoration and non-data pixels should be limited in a dashboard to avoid distraction from the real purpose of the dashboard (Few, 2006). We have therefore not used any form of decoration when designing the dashboard and we have attempted to limit the non-data pixels such as white spaces in graphs that do not add meaning to the data. The choice for colors in the dashboard has been based on the theory of Few (2006) where he mentions that less saturated colors should be used and saturated colors only have purpose when they are used to show an alerting situation. We have therefore decided that the background is white and the only saturated colors we use are bright red or lighter red to alert the users. These are all the visual features that the dashboard is based on. The following paragraphs will discuss the functional features of the dashboard.

The first functional feature we have added to the dashboard is automatic alerts. Eckerson (2005) has mentioned that a relevant functional feature is that the user is automatically alerted to business situations that are in need of attention from the user. In the case of the dashboard for Bluetron, there are multiple business situations which trigger alerts on the dashboard:

- NDF Pass
  The background behind the ranking meter of the KPI NDF Pass will become red when the value of the KPI is either lower than 15% or higher than 24%.
- NDF Fail
  The background behind the ranking meter of the KPI NDF Fail will become red when the value of the KPI is either lower than 76% or higher than 85%.
- Extern
  When there are tape drives that hold the status 'extern' longer than 14 days, a table will appear showing the article number of this tape drive together with the number of days this tape drive already holds the status 'extern'. The background behind this table will become red to draw attention to the KPI. When there are no tape drives that hold the status 'extern' longer than 14 days, the dashboard will show a thumb that indicates a good situation.
- Packed
  When there are tape drives that hold the status 'packed' longer than 14 days, a table will appear showing the article number of this tape drive together with the number of days this tape drive already holds the status 'packed'. The background behind this table will become red to draw attention to the KPI. When there are no tape drives that hold the status 'packed' longer than 14 days, the dashboard will show a thumb that indicates a good situation.
- Number of complaints
  In the case that the number of complaints in a month is higher than 3, the number will become red and the background behind this number as well to draw extra attention to the KPI.

Another functional feature that Eckerson (2005) has mentioned is the filter feature. During the focus group on KPI selection with four employees, we have already determined that the employees of Bluetron should be able to filter the data shown on the dashboard based on the month and based on article numbers. This was determined, because different article numbers have different characteristics and different demands. It is therefore of great value to Bluetron to be able to filter the data on article number.

Yigitbasioglu and Velcu (2012) mention that the drill-down feature is a critical component of a dashboard. We therefore argue that the dashboard should contain this feature, such that the user can access raw data within the dashboard. This way, the user can look at both the general status of the tape drive test process as well as detailed information about for example the status of a single tape drive. The scope of this research did not allow us to incorporate this feature into the dashboard design. Based on the literature suggestions, we do, however, recommend that in the future Bluetron incorporates the feature into the dashboard design.

These are the functional features the dashboard design will contain. Figure 19 shows the dashboard without alerting business situations and Figure 20 shows the dashboard design with alerting situations. The real dashboard can of course display a combination of these two dashboard designs, because the KPIs do not have to be alerting at the same time.

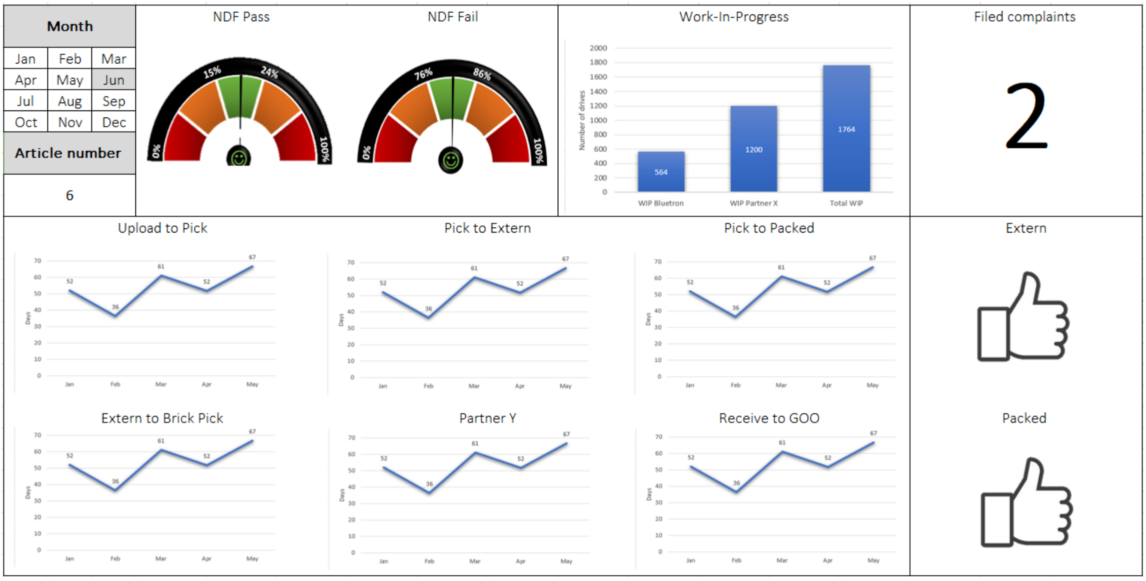


Figure 19 Dashboard design without alerting business situations

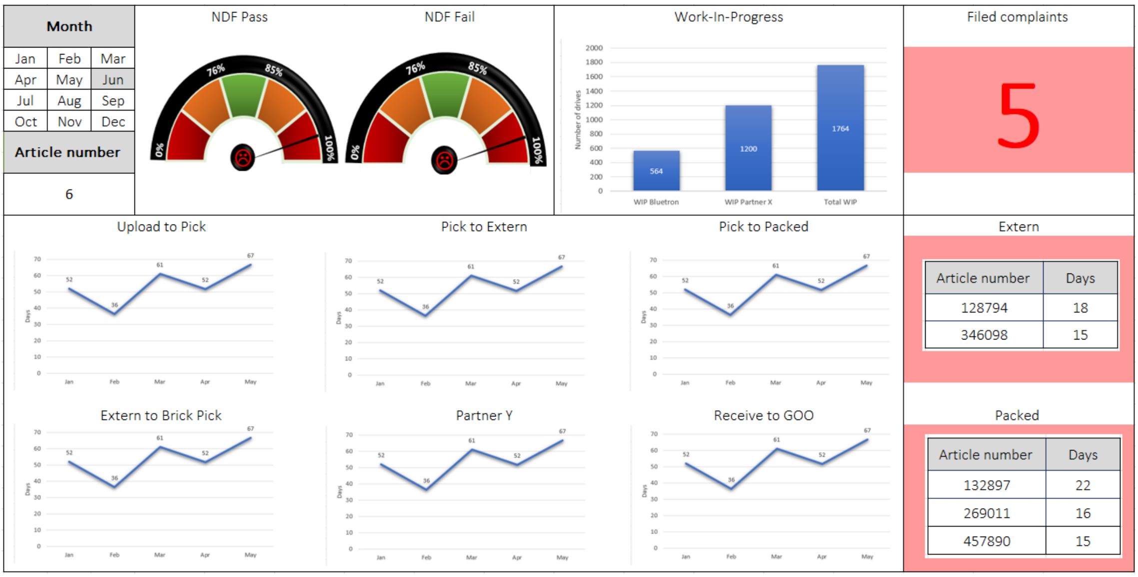


Figure 20 Dashboard design with alerting business situations

Chapter 6 Implementation

This chapter discusses the dashboard prototype and the proposed method to promote a supportive attitude towards the introduction of this prototype. The dashboard prototype is discussed in Section 6.1 'Dashboard Prototype'. To become knowledgeable about employee acceptability of a new artifact, we performed a Systematic Literature Review, which is described in Section 6.2 'Employee Acceptability'. Based on this knowledge, we describe the 8-step change model by Kotter (1996) for the dashboard prototype at Bluetron, which we mention in Section 6.3 'Change Model'.

6.1 Dashboard Prototype

Based on the proposed dashboard design in Section 5.2 'Design', a dashboard prototype has been developed. Figure 21 shows a screenshot of this prototype. The dashboard displays all the KPIs from the dashboard in Figure 19, except from the KPI 'filed complaints'. For this KPI to be calculated, the ERP system of Bluetron has to be updated. This update cannot be applied within the scope of this thesis and therefore the KPI 'filed complaints' is not displayed on the dashboard prototype. Moreover, there are slight discrepancies, for instance we recommended the KPIs 'packed' and 'extern' to be displayed with a table, but the company was limited to the use of numbers for these KPIs.

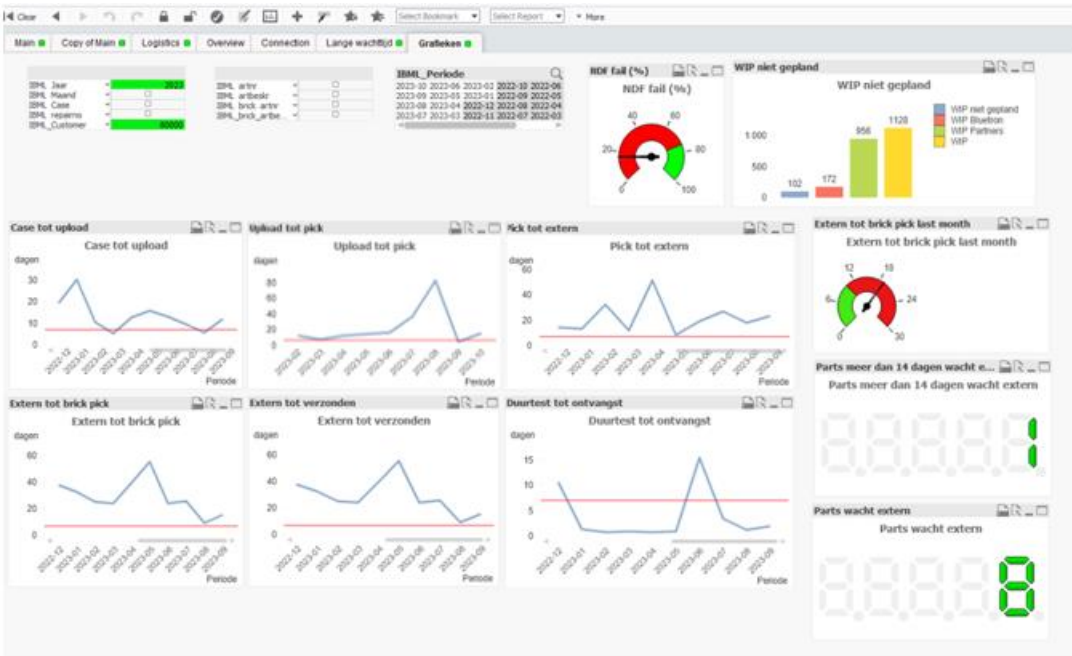


Figure 21 Screenshot of the dashboard prototype

6.2 Employee Acceptability

In the previous chapter we have designed a dashboard displaying KPIs to create insight into the bottlenecks of the tape drive test process at Bluetron. This dashboard, however, means a change in the way of working and needs to be used at Bluetron in the correct manner. This is of importance because the success of a dashboard is very dependent on the way they are used in organizations (Yigitbasioglu & Velcu, 2012). Moreover, the utilization of a dashboard is very dependent on the acceptability of employees (Garvin, 2000). Having a strong technical solution does not guarantee a successful implementation (Mento, Jones & Dirndorfer, 2002). Jick (1991) states in his research that gaining employee acceptability is very challenging, as people are generally resistant to any change, whether it is positive or negative. People most often are satisfied with the status quo, because the known is interpreted as comfortable. While overcoming resistance to change is a difficult task, companies should put effort into change management. They are required to make changes due to constantly changing circumstances, such as technology that is continuously being improved (Errida & Lotfi, 2021). To make sure that the dashboard prototype at Bluetron will be accepted by the employees, we employ a change model. As literature suggests that issues related with human factors are more challenging than technical issues, we will focus on change models with emphasis on employee acceptability. The approach for this Systematic Literature Review on employee acceptance of technical artifacts is explained in Appendix F 'SLR Employee Acceptability'.

As stated before, a new dashboard will introduce change at Bluetron. To promote a supportive attitude towards change, a suitable change model should be utilized. Mento, Jones and Dirndorfer (2002) mention three models in their review on influential change management models: The 8-step model by Kotter (1996), the 10-step model by Jick (1991) and the 7-step change model by General Electric (Garvin, 2000). These three models all lie emphasis on employee acceptability rather than on technical aspects. However, Kotter's model separates itself from the rest by incorporating short-term wins into the model. Short-term wins are deemed very important for the acceptability of employees (Stouten, Rousseau and De Cremer, 2018; Kotter, 1996). Moreover, the 8-step model by Kotter is frequently used in the literature in the context of change management. Therefore we have chosen the model by Kotter to form the basis for the implementation of the dashboard prototype at Bluetron.

The model by Kotter (1996) consists of 8 steps: 1) Create a sense of urgency, 2) Forming powerful guiding coalitions, 3) Developing a vision and a strategy, 4) Communicating the vision, 5) Removing obstacles, 6) Creating short-term wins, 7) Consolidating gains, and 8) Anchoring change in the corporate culture (Kotter, 1996). In the following section, 6.3 'Change Model', we will apply this model to the situation at Bluetron.

6.3 Change Model

This section further elaborates on the 8-step change model by Kotter as discussed in Section 6.2 'Employee Acceptability'. The change model has been applied to the change process Bluetron will have to go through, namely the utilization of the dashboard. Bluetron is currently going through a restructuring process, where the current structure is changed to a structure involving business units. The tape drive test process will become a business unit on its own. The employees that have been involved in this research will still be involved with the tape drive test process in the future. The rest of the composition of the business unit, however, is still unknown. The dashboard prototype has thus not yet been implemented, but has only been tested at Bluetron.

1. **Create a sense of urgency**

The first step of the model by Kotter, 'create a sense of urgency', is a vital step for the success of a change process, as Kotter (1996) argues that the need for change must be understood: 'change agents will otherwise not have enough power and credibility to initiate the required change program' (Kotter, 1996). As an external source can strengthen the message of the change agent (Armenakis, Harris & Mossholder, 1993), this thesis contributes to the creation of a sense of urgency y being an external source that tells Bluetron change is needed. Moreover, Jansen (2004) argues that discussions about change indicate that change is progressing. During the interviews and the focus group on KPI selection with the four employees involved with the tape drive test process, a lot of discussions have taken place. The employees eventually agreed that change in the form of a dashboard is needed. To conclude, through the conduction of this research, the interviews, and the focus group, the sense of urgency for change is already created.

2. **Forming powerful guiding coalitions**

After the sense of urgency is created, according to Kotter the main task should be to form a powerful guiding coalition. One person is generally not capable of single-handedly managing the change process and thus putting together the right guiding coalition of people is critical (Kotter, 1996). As Bluetron is going through a restructuring phase, the composition of employees that will be involved with the tape drive test process is not known by Bluetron yet. Therefore, we cannot completely put together the guiding coalition, but in the future the guiding coalition should consist of employees with the following characteristics: position power, expertise, credibility, and leadership (Kotter, 1996). As the employees that have been involved in this research are already aware of the urgency of the dashboard, they can initially be part of the guiding coalition. When the business unit is complete, other employees can also enter the coalition under the condition that the necessary characteristics are present.

3. **Developing a vision and a strategy**

Step 3 is to develop a vision and a strategy for the change, in this case the utilization of the dashboard prototype. Kotter (1996) states that an effective and clearly defined vision is essential for change to be successful. In the early stages of this research, the vision as well as the strategy have already been determined. The vision for Bluetron and in particular for the tape drive test process is that in the future bottlenecks can be located. The strategy for achieving this vision is to create a dashboard. This thesis provides guidelines for Bluetron to create and use this dashboard. The conclusion is thus that the vision as well as the strategy are already determined and that the strategy has been well defined in this thesis in Chapter 4 'KPI Selection and Visualization' and Chapter 5 'Dashboard Design'.

4. **Communicating the vision**

In the previous step of the 8-step change model by Kotter, we described the vision for change. Bordia et al. (2004) argue that communication of this vision should not be forgotten as it reduces the uncertainty of the change process. Nelissen and van Selm (2008) found in their research that there exists a significant correlation between employee acceptability and management communication. The guiding coalition should thus communicate the vision and the progress towards this vision. Kotter (1996) agrees with this statement as he mentions that two-way communication yields more result than one-way communication and that face-to-face communication in a group context can be key for integrating change successfully. Therefore, as the literature suggests, the employees involved with the tape drive test process should meet face-to-face when the business unit is complete and the guiding coalition should communicate the vision while allowing for two-way communication.

5. **Removing obstacles**

Successful communication of the vision often encourages employees to try new approaches (Kotter, 1996). Communication, however, is often not sufficient by itself and should be complemented by removing the obstacles to the change vision (Kotter, 1996). Three major obstacles mentioned by Kotter (1996) are the following: skills, systems, and supervisors. To overcome the obstacle 'skills', the employees should be trained to correctly use the dashboard. The obstacle 'systems' is an obstacle that is currently an issue at Bluetron. At the moment, there are not sufficient licenses for the BI platform for the employees at Bluetron. This results in employees not being able to access information that isuseful to them. To overcome this obstacle, Bluetron should invest in more licenses for the BI platform. As for the obstacle 'supervisors', Kotter (1996) provides a solution in his research, namely that supervisors should give employees an empowering opportunity, such asleading a meeting or being responsible for the execution of a certain task. This way, employees feel heard and respected by the supervisors. As a conclusion, to remove obstacles Bluetron should train employees to use the dashboard, purchase more licenses for the BI platform, and provide employees with empowering opportunities

6. Creating short-term wins

The previous steps have focused on communication and adjusting the situation at Bluetron such that change can be implemented. The 6th step of the change model by Kotter is to create short-term wins, which is deemed as crucial for the acceptability of employees by Stouten, Rousseau and De Cremer (2018). Pietersen (2002) states that early victories create self-confidence and builds up momentum towards long-term goals. As the purpose of the dashboard is to create insight into the bottlenecks of the tape drive test process, short-term wins at Bluetron are finding bottlenecks, regardless of their size.

7. Consolidating gains

When short-term wins have been created, Kotter (1996) mentions that it is critical for the guiding coalition to use these wins to tackle other issues, such as systems that do not complement the change vision. Moreover, the leaders need to prove that the new way is working (Kotter, 1996). This means for Bluetron that employees should see real improvements, i.e. the location of bottlenecks in the process can be found relatively easy and in a short amount of time with respect to the time it normally takes.

8. Anchoring the change in the corporate culture

Kotter (1996) argues with the last step of his change model that it should be ensured that the change lasts on the last term, in the way that the change is implemented in the culture of the company. Kotter (1996) describes two critical factors for the institutionalization of the change vision in the culture of companies: the first factor is to show employees how the change has contributed to improved performance and the second factor is to ensure that the next generation of management also is an advocate for the change vision. Bluetron should thus make the use of a dashboard, if proven successful, the standard way of working for the tape drive test process and make sure that new employees also see the value of the use of dashboards.

Chapter 7 Evaluation

With this evaluative chapter, we want to check whether or not the objectives that were set in the beginning of the research in Section 1.2.6 'Problem Quantification' have been reached by the introduction of the dashboard design.

The first objective is effectiveness, which is expressed in terms of (1) the completeness of the data that is generated during the test process, (2) the ability to clearly interpret the information about the test process, and (3) the ability to convey complete insight into the bottlenecks of the process. The second objective is efficiency, which is expressed in terms of the time consumed by employees to gather insight about the tape drive test process. The third objective is the ability of the dashboard prototype to support locating bottlenecks in the tape drive test process.

We evaluate the first and the second objective after the introduction of the dashboard prototype by conducting a survey among four employees. To avoid possible bias in the questions, we have chosen to use the same statements and the Likert scale that were used to determine the initial values of the objectives in the starting situation. Appendix G 'Survey Evaluation' shows the contents of the survey. We also conducted semi-structured interviews with the employees who filled in the survey to further explore the opinion of the employees and to give them the opportunity to substantiate the scores they have given in the survey. We evaluate the third objective by first attempting to locate a bottleneck in the tape drive test process with the support of the prototype solution and thereafter eliminate this suspected bottleneck by making an intervention in the tape drive test process. To measure whether the suspected bottleneck we have eliminated is a real bottleneck, we calculate the difference in average throughput time of the tape drives between June and September, before and after the intervention has been made.

The following paragraphs will discuss the four statements with the scores given by the employees and the difference in throughput time before and after an intervention has been made in the tape drive test process.

Effectiveness

The first objective is effectiveness. The survey consists in total of four statements of which the first three together determine the value of this objective. We will discuss the final values of these statements in the following paragraphs.

Statement 1 is the following:

1. *'Enough data is generated during the tape drive test process to be able to gather insight into the bottlenecks of the process.'*

Table 7 shows both the the initial values and the final values of this statement as perceived by the employees in the second row, where the second until the sixth column show the initial values and the seventh until the eleventh column show the final values of the statement, which is shown in column 1. The numbers in columns 2 until 11 represent the number of employees that assigned a certain score to the statement. Table 7 shows that the effectiveness in terms of data generation increased with a relatively small amount, due to the high initial values. Employees already believed that a lot of data was generated during the process and that there was little to no room for improvement. Because one small step was added to the process to make the data generation for the dashboard complete, some of the employees gave a slightly higher score, where others think the situation with regard to data generation has remained consistent. The dashboard design has thus slightly improved data generation, with an average increase of 0.25 on the Likert scale.

The second statement with regard to effectiveness is stated below:

2. *'The generated data is transferred to clearly interpretable information about the tape drive test process.'*

Table 7 shows the initial values and the final values for the second statement in the third row. Table 7 shows that the initial values are relatively low, namely 2, with one outlier, namely 5. Most of the employees thus agree that the information was not clearly interpretable, while one employee believes that the information is clearly interpretable. The final values are, however, very consistent, namely a 4 or a 5. During an interview about the objectives, an employee mentioned that 'with the way you present the information in the dashboard, the majority of the employees will understand the data with no further explanation needed.' Moreover, another employee said the following: 'If I look at this dashboard, it is very easily interpretable. I do not have to think about the meaning, I can right away act on this information'. These remarks explain the high final values for the third statement and it can be concluded that the dashboard has contributed to the improvement of the data interpretability with an average increase of 2 on the Likert scale.

The last statement that measures the effectiveness is the following:

3. *'The generated data is transferred to clearly interpretable information which gives a complete insight into the bottlenecks of the tape drive test process.'*

Table 7 shows the initial values and the final values for this statement as provided by the employees in row 4. Table 7 shows that the employees were in agreement about the third statement during the initial evaluation, namely that the current situation did not provide a complete insight into the bottlenecks of the tape drive test process. The final values in Table 7 show that the employees again are in agreement about the statement. They believe that the dashboard design has improved the situation in the way that they now have the ability to gather a nearly complete insight into the bottlenecks of the process. One employee mentioned during the interview about the statements that 'we're not yet at a complete insight, but we are heading towards this with the dashboard. It is a good step of improvement for Bluetron.' We therefore conclude that the dashboard design improves the ability to gather a complete insight into the bottlenecks of the test process of tape drives with an average increase of 2.5.

Efficiency

The second objective is efficiency, which we have expressed in terms of time consumed by employees to gather insight into the bottlenecks of the test process of tape drives. We have created one statement that will determine the value for the third objective. We will discuss the final value of this statement in the paragraphs below.

The statement that was included in the survey to measure the value for efficiency, is the following:

4. *'I need the minimal amount of time to acquire clearly interpretable information which gives insight into the bottlenecks of the tape drive test process.'*

Table 7 shows the initial and the final values for this statement as perceived by the employees in the fourth row. Table 7 shows that in the current situation the employees all disagree with the last statement about time needed to gather insights into the bottlenecks of the tape drive test process. The table also shows that, with the introduction of the dashboard design, the employees all agree with the statement. They believe that the dashboard design can save them a lot of time in locating bottlenecks. One employee mentioned the following with regard to the fifth statement: 'I am convinced that the dashboard is of great importance to the process. It will certainly save me time with locating errors and bottlenecks.' We can thus conclude that the dashboard design decreases the time needed to gather insight into the bottlenecks, with an average increase of 2 on the Likert-scale.

It is important to note that the dashboard prototype is tested, but not implemented at Bluetron and that the scores of employees are based on expectations and not real-life experiences. The implementation of the dashboard can thus turn out to be more or less successful than described in this evaluation.

Table 7 Scores given by employees at Bluetron to the four statements of the survey about effectiveness and efficiency of the situation without the dashboard prototype and the situation at Bluetron with the dashboard prototype

Statement	Without					With				
	1	2	3	4	5	1	2	3	4	5
1.Enough data is generated during the tape drive test process to be able to gather insight into the bottlenecks of the process.	-	-	-	2	2	-	-	-	1	3
2.The generated data is transferred to clearly interpretable information about the tape drive test process.	-	3	-	-	1	-	-	-	1	3
3.The generated data is transferred to clearly interpretable information which gives a complete insight into the bottlenecks of the tape drive test process.	3	1	-	-	-	-	-	1	3	-
4. I need the minimal amount of time to acquire clearly interpretable information which gives insight into the bottlenecks of the tape drive test process.	2	2	-	-	-	-	-	2	2	-

Ability to support locating bottlenecks

The third objective is the ability of the dashboard prototype to support locating bottlenecks in the tape drive test process at Bluetron. As a measure, we use the average total throughput time per tape drive in days to determine whether the prototype complies to the third objective. If the average total throughput time decreases after the dashboard prototype is tested by attempting to locate and eliminate bottlenecks, the prototype complies with the third objective, namely, the ability to support locating bottlenecks. The starting situation is in June, when the dashboard prototype was introduced, but not yet tested. Table 8 shows the average throughput times per tape drive in June for the 6 parts of the process that are shown in BPMN models in Section 2.1 'Process'. The first column shows the parts of the process, and the second column shows the average throughput time in June.

With support of the dashboard prototype we were able to spot a suspected bottleneck in the 'Extern to Brick Pick' part of the process. Subsequently, an intervention has been made to attempt to eliminate this suspected bottleneck. To measure whether this suspected bottleneck really is a bottleneck, the average throughput time per tape drive in the 'Extern to Brick Pick' part of the process has to decrease after the intervention has been made as well as the average total throughput time, to avoid local optimalization only. We compare the average throughput times per tape drive in September with the average throughput times per tape drive in June, as the intervention has been introduced at the end of August. This way, we measure whether the throughput time has decreased and thus whether a real bottleneck has been eliminated. According to an employee at Bluetron, there was no other significantly influential factor present in this period of time that could have caused this decrease.

Table 8 shows that average throughput time ‘Extern to Brick Pick’ has decreased with 10 days and total average throughput time has decreased with 12 days. The decrease in the ‘Extern to Brick Pick’ part of the process, the part in which an intervention has been made, accounts for approximately 83% of the decrease in the total tape drive test process. We can conclude that the suspected bottleneck found by the support of the dashboard prototype is a bottleneck that has been subsequently eliminated. The dashboard prototype has thus proven that it supports locating bottlenecks in the tape drive test process at Bluetron.

Table 8 Average Throughput times in days in June and September and the difference

Part of Process	**Average Throughput Time (days)**		**Difference**
	June	**September**	
Upload to Pick	11	12	+1
Pick to Extern	17	17	0
Pick to Packed	20	21	+1
Extern to Brick Pick	22	12	-10
Partner Y	18	16	-2
Receive to GOO	5	3	-2
Total	**93**	**81**	**-12**

Chapter 8 Conclusion and Recommendations

This is the closing chapter of this thesis where we discuss the findings of this research. Section 8.1 'Conclusion' provides answers to the sub questions and the main research question. Section 8.2 'Recommendations' mentions recommendations for Bluetron based on the research findings and experience. Section 8.3 'Restrictions' discusses the validity, reliability, and limitations of this research. Lastly, Section 8.4 'Scientific Relevance' describes the contribution to the theory together with possibilities for future research.

8.1 Conclusion

Stated below is the main research question for this thesis:

'How can the bottlenecks in the tape drive test process at Bluetron be measured and monitored using a KPI dashboard?'

By following the guidelines described in this research, the bottlenecks in the tape drive test process can be measured and monitored using a KPI dashboard. The guidelines include KPI selection through the Analytic Hierarchy Process in combination with the SMART goal-setting theory and the criteria for visualization of these KPIs based on the aim of the visualization. Moreover, the guidelines incorporate advice on dashboard design based on principles discovered in academic sources and the promotion of a supportive attitude towards the dashboard by using the 8-step change model by Kotter (1996). By following these guidelines, the bottlenecks of the tape drive test process at Bluetron are measured and monitored through the use of a KPI dashboard. We substantiate this answer by answering the sub questions stated in this research.

1. **What does the current test process of tape drives look like?**

The current test process of tape drives is visualized in BPMN models in Figures 3, 4, 5, 6, 7, and 8 in Section 2.1 'Process'. To reach this representation, our research initially involved a comprehensive examination and description of the tape drive test process at Bluetron. In the early stages, we attempted to capture the entire process in a single BPMN model, but this approach resulted in confusion both among Bluetron employees and ourselves. Consequently, we made the decision to break down the process into six distinct stages, namely 'Receiving and Distributing,' 'Testing,' 'Repairing,' 'Partner Y,' 'Checking,' and 'Returning.' This restructured approach allowed us to achieve a more in-depth understanding of each stage, aligning better with the complexity of the tape drive test process at Bluetron.

2. **What insights into the bottlenecks of the test process of tape drives does Bluetron currently have ?**

Currently, Bluetron possesses insights, in terms of available KPIs, into the bottlenecks of the test process as revealed in Table 2 in Section 2.2 'Available KPIs'. Moreover, Bluetron employees currently face challenges in effectively and efficiently gaining insights into the bottlenecks of the test process. To discover the available KPIs, we analyzed the ERP system and BI platform of Bluetron. Furthermore, we aimed to establish a baseline for our first two objectives, 'effectiveness' and 'efficiency'. 'Effectiveness' is expressed in terms of (1) the completeness of the data that is generated during the test process, (2) the ability to clearly interpret the information about the test process, and (3) the ability to convey complete insight into the bottlenecks of the process. 'Efficiency' is expressed in terms of the time consumed by employees to gather insight about the tape drive test process. To measure these two objectives, we conducted a survey consisting of four statements. The results from the survey, shown in Table 3 in Section 2.3 'Initial Values Objectives', made that we shifted the focus of our research towards enhancing data interpretation, ensuring a complete insight into the bottlenecks of the tape drive test process, and reducing the time required to gain a clear insight into these constraints.

3. **What is a relevant method to select KPIs for the dashboard design?**

The Analytic Hierarchy Process by Saaty (1988) in combination with the SMART goal-setting theory (Shahin & Mahbod, 2007) stands out as a relevant method for selecting KPIs for the dashboard design. To arrive at this selection, we conducted a Systematic Literature Review on KPI selection methods, identifying a diverse range of approaches in the literature. The low dependence on expert opinions and the allowance for the incorporation of clear and measurable goals are the reasons that we chose the abovementioned methods. It is, however, crucial to note that within the scope of this research, we focused on a single KPI selection method, while recognizing that there may be alternative, possibly more suitable approaches.

4. **What are the criteria for choosing relevant visual representations for KPI dashboards?**

Table 4 in Section 3.2 'KPI Visualization Choices' provides the criteria for matching KPIs with appropriate visualizations based on type of visualization and KPI objectives. To establish these criteria, we conducted a Systematic Literature Review, during which we discovered relevant theories. It is essential to note that the evaluation of the chosen visualizations against metrics of effectiveness, expressiveness, readability, scalability and interactive visualizations, as proposed by Halim & Tufail (2017), is not within the scope of this research. This, however, is an interesting direction for future research as it can offer valuable insights into the suitability of these visual representations and their alignment with the goals of the dashboard.

5. **What are the most relevant KPIs for the dashboard for Bluetron that measure and monitor bottlenecks?**

Table 6 in Section 4.1.4 'SMART Analytic Hierarchy Process' provides the selected KPIs, highlighted with green rows, as identified through the application of our chosen KPI selection method. To arrive at these selections, we began by assembling a pool of potential KPIs through a combination of literature review and semi-structured interviews with employees, as outlined in Table 6. Subsequently, during a focus group session hosted at Bluetron, we implemented the Analytic Hierarchy Process in combination with the SMART goal-setting theory to further refine our KPI choices. Furthermore, this focus group session brought to light the necessity of breaking down the KPI Throughput time at Bluetron into five distinct KPIs, each corresponding to various stages in the tape drive transfer process between departments. An insight that emerged during this focus group was the realization that while the Analytic Hierarchy Process appeared theoretically suitable for KPI selection at Bluetron, practical application required slight adjustments to ensure that the method revealed the most relevant KPIs for Bluetron employees.

6. **What are relevant visual representations for the KPIs selected for the KPI dashboard?**

The KPIs NDF Fail and NDF Pass are ranking type metrics, Extern and Packed were chosen to be represented in tabular formats, Number of Complaints is represented with a numeric representation of an integer, 'Work-In-Progress' was chosen to be a bar chart, and the 'Throughput Time Bluetron' and 'Throughput Time Partner Y' were chosen to be line charts to additionally convey the trends. We used the answer of the previous question, the criteria for visualizations, to determine the relevant visual representations for the selected KPIs.

7. **How can the visualizations for the different KPIs that we have chosen for the detection of bottlenecks be combined in a dashboard view to enable effective monitoring?**

By placing the most important KPI in the top-left corner of the dashboard, minimalizing non-data pixels, using less-saturated colors and integrating automatic alerts, filter features and drill down features, visualizations can be combined in a dashboard view to enable effective monitoring. A Systematic Literature Review provided us with these insights, mostly drawing from the works of Few (2006), Bach (2022), Dinmohammad and Wilson (2021), and Eckerson (2005). Figures 19 and 20 in Section 5.2 'Dashboard Design' shows the resulting dashboard design. However, even though this dashboard design is based on principles found in the literature, only one option is explored. We therefore cannot say that this design is optimal and that alternative design possibilities might exist.

8. **How can we promote a supportive attitude towards the introduction of the KPI dashboard?**

We adapted the 8-step change model by Kotter (1996) to Bluetron's specific context, which includes the formation of a guiding coalition, communication of the vision, the removal of obstacles, and the creation of short-term wins. As our research progressed, we recognized the pivotal role of employee acceptance and their attitude in the success of technological implementation. This understanding led us to prioritize strategies that emphasize these aspects over purely technical solutions. Hence, we conducted a Systematic Literature Review on employee acceptance and attitude. However, it's crucial to acknowledge that this approach, while valuable in promoting employee acceptability, places relatively less emphasis on the technological aspects of dashboard implementation, potentially impacting the level of support received for these technical dimensions at Bluetron.

9 **Did the prototype built following the guidelines of this thesis comply with the objectives we have set, namely effectively and efficiently detecting bottlenecks in the tape drive test process?**

The prototype built following the guidelines of this thesis has met the objectives we set for effectively and efficiently detecting bottlenecks in the tape drive test process. Through both survey responses and semi-structured interviews, it became evident that the introduction of the dashboard design led to improved data generation, data interpretability, completeness of information about bottlenecks, and reduced time required for employees to gain a comprehensive insight into test process bottlenecks. Furthermore, the prototype showed its ability to identify bottlenecks in the tape drive test process, as demonstrated by a significant improvement of 12 days in the average total throughput time per tape drive between June and September, before and after the introduction of the intervention. While this reduction can be partially attributed to factors such as increased staff or reduced work-in-progress in September, an employee at Bluetron deems these factors less influential than the intervention and assigns 83% of the reduction to the elimination of the bottleneck. Nevertheless, it is essential to critically consider that the real-world success of the dashboard may deviate from this evaluation since the actual implementation of the prototype has not yet occurred.

8.2 Recommendations

Having worked on this research project for approximately six months, we have developed insights into Bluetron, and in particular into the tape drive test process. Based on this research, we discuss a number of recommendations for Bluetron with regard to the dashboard design for locating bottlenecks in the tape drive test process.

- *KPI Selection*

In the first stage of creating an effective bottleneck-locating dashboard, it is imperative to carefully select tailored Key Performance Indicators (KPIs) for that goal. The KPIs offered within this research constitute the initial recommendations. To adapt and expand them to fit a broader context, the company representatives (both for Bluetron but also companies with similar contexts in general) is advised to begin by conducting a comprehensive literature review, as suggested by Dwivedi and Madaan (2020). Additionally, the company will need to seek expert opinions, as advised by Marr (2012). To prioritize KPIs, the company may need to employ a structured technique such as the Analytic Hierarchy Process (AHP) by Saaty (1988) in conjunction with the SMART goal-setting theory proposed by Shahin and Mahbod (2007). Based on our research, a list of KPIs to incorporate into the dashboard includes NDF Fail, NDF Pass, Booked external, Packed, Number of complaints, Work in Progress for both Bluetron and Partner Y, as well as Throughput time for both entities. As stated earlier this list of KPIs is not necessarily the final list of KPIs. As organizations are constantly changing, e.g. through technical innovation as the company is operating in a rapidly developing environment, relevant KPIs should thus be adapted according to the changing situation. For that reason, we recommend that the employees at Bluetron continuously evaluate the KPIs displayed on the dashboard and adapt accordingly. The Design Science Research Methodology which we used in this research to create the dashboard design can be used for this continuous (re-)evaluation and refinements of KPIs (Peffers et al., 2007). The methodology encourages to reiterate the 6 steps to eliminate errors and to adapt the artifact to possibly changing circumstances and can therefore be used by Bluetron to evaluate the KPIs displayed on the dashboard.

- *KPI Visualization*

To effectively visualize selected KPIs, the insights drawn from Lebanon and El-Geish (2018), Stoltzman (2018), and Zelazny (2001) can be used. Table 4 in Section 3.2 'KPI Visualization Choices' is a table that aligns types of visualizations with specific criteria based on the aims of a visual representation, such as comparison, relationship, distribution, and others. Our research findings suggest the following visualizations: the dashboard may employ a ranking meter for NDF Fail and NDF Pass, use a table for Extern and Packed, represent Number of Complaints as a number, visualize Work-In-Progress with a bar chart, and employ line charts for displaying Throughput times. We also recommend to determine the suitability of the chosen representations in the future by using a metrics, e.g. the metrics discussed by Halim and Tufail (2017) based on effectiveness, expressiveness, readability, and interactivity.

- *Dashboard Design*

When designing the dashboard, based on the findings of this research the company is advised to consider both visual and functional features. Our research, influenced by Few (2006), Bach et al. (2022), Yigitbasioglu and Velcu (2012), Dinmohammad and Wilson (2021), and Eckerson (2005), recommends that the dashboard should fit within a single screen for enhanced user interaction, avoid unnecessary decoration and non-data pixels, and position the most critical KPI in the top-left corner. General guideline is to arrange graphs adjacent to each other for easy comparison and use saturated colors. Functionally, the suggested guideline is to incorporate automatic alerts to highlight critical situations, implement filtering options for data customization, and provide drill-down capabilities for access to raw data. Based on the literature, we created a dashboard design shown in Figure 19 in Section 5.2 'Dashboard Design'.

- *Implementation*

In the final stage, to ensure employee acceptance and usability of the dashboard design Bluetron is recommended to draw from Kotter's 8-step change model (1996) which particularly focuses on the concept of employee acceptability. This model suggests creating a sense of urgency for change, forming powerful guiding coalitions, developing a vision and strategy, communicating this vision, removing obstacles for employees, creating short-term wins, consolidating gains, and anchoring the change in the corporate culture. Our research findings, detailed in Section 6.3 'Change Model', have customized this model for Bluetron. However, it is important to note that before promoting a supportive attitude towards the dashboard, Bluetron should consider its current restructuring phase, which may impact its ability to form a guiding coalition effectively.

8.3 Restrictions

8.3.1 Validity and Reliability

This research deals with both quantitative and qualitative research. For quantitative research, validity refers to the accuracy of a measure and reliability refers to the consistency of a measure (Golafshani, 2015). This research deals with KPIs, which are metrics that can measure performance. As validity refers to the accuracy of a measure, the validity of KPIs refers to the accuracy of the chosen KPIs with respect to the intended goals. Accuracy refers to how close a measurement is to the true value ((*Practices of Science: Precision Vs. Accuracy,* n.d.). To ensure this accuracy, the selected KPIs have been evaluated by employees at Bluetron on the effectiveness and efficiency with which they portray the performance of the process with respect to bottlenecks. This has been done by a survey that was filled in by four employees. Moreover, the values of the KPIs have been compared to real-life situations to ensure that the KPIs portrayed the true value. To ensure the consistency of the measure, i.e. the reliability, in the survey, we have asked the employees to fill in the same survey twice: before and after the introduction of the dashboard design. We based the survey on the research of Roopa and Rani (2012) about the design of surveys to make an attempt to ensure consistency of the measures.

The throughput time of the test process before and after the introduction of the dashboard prototype is relevant quantitative data for this research. To ensure that the improvement of the throughput is caused by (1) locating and (2) eliminating a bottleneck (3) which is found with the dashboard prototype, we talked with an employee at Bluetron. This employee is involved with the tape drive test process on a daily basis and mentioned that the decrease in throughput time was caused by the intervention, as there was no other significantly influential factor present in this period of time that could have caused this decrease.

The rest of our research design is mostly focused on qualitative research. Golafshani (2015) concludes in her research that the quality of a study in a paradigm should be evaluated by its own paradigm's terms. Noble & Smith (2015) state four criteria to evaluate the reliability and validity of research findings in their paper on qualitative research: truth value, consistency, neutrality, and applicability. In the following paragraphs, we will discuss these criteria and how we attempted to comply with these criteria.

The truth value of research is based on the knowledge that there are multiple realities and that different perspectives should be represented (Noble & Smith, 2015). To ensure the truth value, all employees that are involved with the test process of the tape drives have been involved in the research. Both operations employees and back office employees have been interviewed and taken into account to cover all different perspectives. In addition, we have asked for feedback on the research findings from the participants with a survey and interviews.

Consistency within research is about the trustworthiness by which the methods have been undertaken, which depends on the clarity and transparency of the researcher's decisions (Noble & Smith, 2015). To comply with this criteria, we have based the design and conduction of all interviews for this thesis on the research by Bolderston (2012) on the conduction of research interviews and on the research by Taherdoost (2022) on interview design in research. Moreover, we have audio recorded the interviews such that we could revisit data and check the questions we asked. Additionally, with this written thesis we provide a clear and transparent description of the research methods used.

The third criterium for reliability and validity used by Noble & Smith (2015) is neutrality, which they explain to be the acknowledgment of the complexity of engagement with participants and that findings can be connected with the researcher's perspective. To neutralize a researcher bias, the chosen KPIs and dashboard design have been evaluated against intended goals, in this case creating insights into bottlenecks, using a representative sample when conducting interviews.

Applicability is the last criterium and refers to the fact whether or not the research findings can be applied to contexts other than the research's context (Noble & Smith, 2015). The research context in this case is the tape drive test process at Bluetron. As research suggests, there are possibilities for the generalizability of qualitative research (Carminati, 2018). For generalization, the purpose of researchers is to generalize from particulars to theories, and in the course of the analysis, researchers distinguish between information that is relevant for the population in contrast to information that is only relevant for the sample (Polit & Beck, 2010). In the case of this thesis, the sample is Bluetron, active in the test sector, remanufacturing sector, and the outsourcing sector, and the population is these sectors together.

The dashboard prototype that has been created for Bluetron is the particular, but the guidelines this thesis describes for Bluetron for the creation of a dashboard, including KPI selection, KPI visualization, dashboard design, and the implementation, can serve as a theory for the entire population. E.g. the KPIs that were selected for the dashboard in this thesis that are specific to the test process at Bluetron, 'NDF Fail', 'NDF Pass', and the different throughput times, can have more general terms. 'NDF Fail' and 'NDF Pass' can be described for other processes respectively as the 'defect rate' and the 'defect rejection rate', and the throughput times used in this thesis can be described as 'throughput time per department'. As it is not in the scope of this thesis to research whether or not these guidelines are generalizable to another context, we assume that these guidelines for creating a dashboard is information that is relevant for the population. The research findings in terms of the guidelines for the creation of a dashboard for locating bottlenecks in a test process are thus generalizable.

8.3.2 Limitations

Research limitations are weaknesses of the study. The list below shows these limitations.

- The first limitation is the fact that we only tested the dashboard prototype design at Bluetron and not the implemented operational prototype mainly due to the timeframe available for this research. This research is therefore limited to the expectation of the employees about the dashboard prototype, and not their experience with the dashboard. The actual results in real-life setup of the dashboard can therefore differ from the expectation of the success.
- The second limitation is the number of participants of this research, namely 4. This means that the surveys described in Section 2.3 'Initial Values Objectives' and in Chapter 7 'Evaluation' have been filled in by 4 employees. This affects the reliability of the results. These 4 employees do, however, form a representative sample for all the employees involved with the tape drive test process as they together have filled all positions at Bluetron regarding the tape drive test process.
- The third limitation concerns the Design Science Research Methodology. The methodology shows 6 steps that have to be performed to design an artefact. After these steps have been executed, the process has to be reiterated to eliminate errors and to improve the design. Due to time restrictions, this research is limited to one cycle of the DSRM and the dashboard will thus have to be improved in the future by the employees at Bluetron themselves.
- This research is constrained by time limitations, which allowed us to identify only one bottleneck in assessing the dashboard's ability in detecting bottlenecks. A broader analysis involving the detection of multiple bottlenecks would have provided a more reliable evaluation, but the timeframe was a limiting factor.
- We created only one dashboard design based on design principles found in literature. To determine an optimal design, more designs would have to be created and tested. This research, however, is limited to the creation and testing of one dashboard design, while acknowledging that other alternatives might be better.
- Within the scope of this research, we were constrained to use a singular KPI selection method, the Analytic Hierarchy Process in conjunction with the SMART goal-setting theory. Although other methods, such as the Analytic Network Process and the Delphi method, appeared to be suitable options, a selection had to be made. To determine the suitability of the methods, all three of these methods would have undergone testing, and the most effective one would have been adopted. This has not been done and therefore this research is limited to our expectation of the suitability of the chosen method.

8.4 Scientific Relevance

This thesis represents a pioneering effort in the field of test sector management by introducing a previously unexplored approach: the development of a dashboard design, guided by the guidelines outlined in this research, specifically aimed at identifying and addressing bottlenecks within testing operations. While there is existing literature on dashboards and their applications across various industries, to the best of our knowledge, we believe that the guidelines mentioned in this research combine different aspects of dashboard creation in a way that has not been done before.

The literature review that has been conducted at the start of this research was also aimed at identifying a gap in literature to which this thesis will contribute. We discovered several works that explored the use of dashboards for the detection of bottlenecks, which however were conducted in different contexts of production lines and supply chains. A limited number of papers were found to have similarities with this thesis. Our approach distinguishes from those works such as Cassim et al.

(2020) and Vilarinho, Lopes, and Sousa (2017) which either focus on a narrower set of KPIs or do not include employee acceptance as crucial component in the dashboard design process. In particular, this thesis extends the scope of KPIs in the domain by including additional KPIs, such as Work-in-Progress, complaints and defect rejection rate. Vilarinho, Lopes, and Sousa (2017) focus on a design procedure for developing dashboards that improve the performance of production processes. Their procedure includes a literature review for KPI selection, visualization of KPIs, and principles for dashboard design, which aligns with our approach and is therefore the most relevant research to compare with. A difference with their method includes our guidelines in selecting KPIs, as we incorporate the Analytic Hierarchy Process for KPI selection, a method not included in the approach of Vilarinho, Lopes, and Sousa (2017). Lastly, the guidelines achieved in the context of this thesis contribute to the particular field of test sector management. It has to be noted though, that the results of this thesis can be applied in generic context for other companies that are specializing in a similar domain. Generalizing into even a broader context outside test management sector may constitute a future research direction.

As mentioned earlier, the findings presented in this thesis also show directions for future research. Firstly, the immediate next step should include the actual implementation of the dashboard prototype within Bluetron. This implementation will provide an opportunity for assessing the real-life effectiveness and usability of the dashboard in locating bottlenecks. Another opportunity for future research is the evaluation of the suitability of the chosen visual representations for the selected KPIs using the metrics proposed by Halim & Tufail (2017) based on effectiveness, expressiveness, readability, and interactivity. Moreover, future research can look at the application of Lean Six Sigma principles to systematically eliminate the located bottlenecks, to improve operational efficiency. Additionally, researching whether the dashboard design principles proposed in this thesis for Bluetron are also applicable to other companies within the test sector is a direction for future research.

References

Ahmed, M. I. (2019). The use of performance-based contracting in managing the outsourcing of a reliability-centered maintenance program. *Journal of Quality in Maintenance Engineering*, *26*(4), 526–554. https://doi.org/10.1108/jqme-02-2018-0007

Amrina, E., & Yulianto, A. (2018). Interpretive Structural Model of Key Performance Indicators for Sustainable Maintenance Evaluation in Rubber Industry. *IOP Conference Series*, *319*, 012055. https://doi.org/10.1088/1757-899x/319/1/012055

Anjomshoae, A., Hassan, A., & Wong, K. Y. (2019). An integrated AHP-based scheme for performance measurement in humanitarian supply chains. *International Journal of Productivity and Performance Management*, *68*(5), 938–957. https://doi.org/10.1108/ijppm-04-2018-0132

Ansari, Z. N., Kant, R., & Shankar, R. (2020). Remanufacturing supply chain: an analysis of performance indicator areas. *International Journal of Productivity and Performance Management*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/ijppm-01-2020-0038

Appelbaum, S. H., Habashy, S., Malo, J., & Shafiq, H. (2012). Back to the future: revisiting Kotter's 1996 change model. *Journal of Management Development*, *31*(8), 764–782. https://doi.org/10.1108/02621711211253231

Armenakis, A. A., Harris, S. G., & Mossholder, K. W. (1993). Creating readiness for organizational change. *Human Relations*, *46*(6), 681–703. https://doi.org/10.1177/001872679304600601

Armstrong, M. (2017). *Armstrong on reinventing performance management: Building a Culture of Continuous Improvement*.

Bach, B., Freeman, E., Abdul-Rahman, A., Turkay, C., Khan, S., Fan, Y., & Chen, M. (2022). Dashboard Design Patterns. *IEEE Transactions on Visualization and Computer Graphics*, 1–11. https://doi.org/10.1109/tvcg.2022.3209448

Bapat, H., Sarkar, D., & Gujar, R. B. (2022). Application of multi-criteria decision making for evaluation of key performance indicators of integrated project delivery and BIM model for an infrastructure transportation project in Western India. *The International Journal of Construction Management*, 1–10. https://doi.org/10.1080/15623599.2022.2040077

Barber, P. W., Pontillo, M., Bellm, E. J. V., & Davies, G. J. (2023). Objective and subjective measures to guide upper extremity return to sport testing: A modified Delphi survey. *Physical Therapy in Sport*, *62*, 17–24. https://doi.org/10.1016/j.ptsp.2023.05.009

Bentley, D. (2017). *Business Intelligence and Analytics*. Library Press.

Bolderston, A. (2012). Conducting a research interview. *Journal of Medical Imaging and Radiation Sciences*, *43*(1), 66–76.

Cai, J., Liu, X., Xiao, Z., & Liu, J. (2009). Improving supply chain performance management: A systematic approach to analyzing iterative KPI accomplishment. *Decision Support Systems*, *46*(2), 512–521. https://doi.org/10.1016/j.dss.2008.09.004

Carlucci, D. (2010). Evaluating and selecting key performance indicators: an ANP-based model. *Measuring Business Excellence*, *14*(2), 66–76. https://doi.org/10.1108/13683041011047876

Carminati, L. (2018). Generalizability in Qualitative Research: A Tale of Two Traditions. *Qualitative Health Research*, *28*(13), 2094–2101. https://doi.org/10.1177/1049732318788379

Cassim, N., Tepper, M. E. E., Coetzee, L. M., & Glencross, D. K. (2020). Timely delivery of laboratory efficiency information, Part I: Developing an interactive turnaround time dashboard at a high-volume laboratory. *African Journal of Laboratory Medicine*, *9*(2). https://doi.org/10.4102/ajlm.v9i2.947

Chen, M., Ebert, D. S., Hagen, H., Laramee, R. S., Van Liere, R., Liu, K., Ribarsky, W., Scheuermann, G., & Silver, D. (2009). Data, information, and knowledge in visualization. *IEEE Computer Graphics and Applications*, *29*(1), 12–19. https://doi.org/10.1109/mcg.2009.6

Dauzère-Pérès, S., Zhan, S., & Chang, S. (2013). Bottleneck-centric pull and push allocation and sequencing of wet-bench and furnace tools. *2013 e-Manufacturing & Design Collaboration Symposium (eMDC)*. https://doi.org/10.1109/emdc.2013.6756048

Day, T. A., & Tosey, P. (2011). Beyond SMART? A new framework for goal setting. *Curriculum Journal*, *22*(4), 515–534. https://doi.org/10.1080/09585176.2011.627213

Dinmohammad, F., & Wilson, D. (Eds.). (2021). *Understanding the End-Users and Technical Requirements for Real-Time Streaming Data Analytics and Visualisation*. University of Portsmouth.

Dwivedi, A. K., & Madaan, J. (2020). A hybrid approach for modeling the key performance indicators of information facilitated product recovery system. *Journal of Modelling in Management*, *15*(3), 933–965. https://doi.org/10.1108/jm2-01-2019-0003

Eckerson, W. W. (2005). *Performance Dashboards: measuring, monitoring, and managing your business*. http://download.101com.com/pub/TDWI/Files/PerformanceDashboards.pdf

Errida, A., & Lotfi, B. (2021). The determinants of organizational change management success: Literature review and case study. *International Journal of Engineering Business Management*, *13*, 184797902110162. https://doi.org/10.1177/18479790211016273

Evergreen, S. D. H. (2019). *Effective Data Visualization: The Right Chart for the Right Data* (2nd ed.). SAGE Publications.

Few, S. (2006). *Information Dashboard Design* (1st ed.). O'Reilly Media.

Frolick, M. N., & Ariyachandra, T. (2006). Business Performance Management: One Truth. *Information Systems Management*, *23*(1), 41–48. https://doi.org/10.1201/1078.10580530/45769.23.1.20061201/91771.5

Ganguly, K. K., & Rai, S. S. (2018). Evaluating the key performance indicators for supply chain information system implementation using IPA model. *Benchmarking: An International Journal*, *25*(6), 1844–1863. https://doi.org/10.1108/bij-03-2017-0041

Garvin, D. A. (2000). *Learning in Action: A Guide to Putting the Learning Organization to Work*. http://ci.nii.ac.jp/ncid/BA46225862

Golafshani, N. (2015). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2003.1870

Gonçalves, C. D. F., Dias, J. a. M., & Cruz-Machado, V. (2014). Decision Methodology for Maintenance KPI selection: based on ELECTRE I. In *Advances in intelligent systems and computing* (pp. 1001–1012). https://doi.org/10.1007/978-3-642-55122-2_87

Gözaçan, N., & Lafci, C. (2020). Evaluation of Key Performance Indicators of Logistics Firms. *Logistics & Sustainable Transport*, *11*(1), 24–32. https://doi.org/10.2478/jlst-2020-0002

Graham, I. J., Goodall, P. A., Peng, Y., Palmer, C., West, A. A., Conway, P., Mascolo, J. E., & Dettmer, F. U. (2015). Performance measurement and KPIs for remanufacturing. *Journal of Remanufacturing*, *5*(1). https://doi.org/10.1186/s13243-015-0019-2

Halim, Z., & Tufail, M. (2017). Quantifying and optimizing visualization: An evolutionary computing-based approach. *Information Sciences*, *385–386*, 284–313. https://doi.org/10.1016/j.ins.2016.12.035

Ho, A., Lai, J. C. S., & Chiu, B. W. (2021). Key performance indicators for holistic evaluation of building retrofits: Systematic literature review and focus group study. *Journal of Building Engineering*, *43*, 102926. https://doi.org/10.1016/j.jobe.2021.102926

Hope, J., & Fraser, R. (2004). Beyond budgeting: how managers can break free from the annual performance trap. *Choice Reviews Online*, *41*(05), 41–2908. https://doi.org/10.5860/choice.41-2908

Jansen, K. J. (2004). From persistence to pursuit: A longitudinal examination of momentum during the early stages of strategic change. *Organization Science*, *15*(3), 276–294. https://doi.org/10.1287/orsc.1040.0064

Jick, T. (1991). Implementing Change : Note. *Harvard Business School*.

Kaganski, S., & Toompalu, S. (2017). Development of key performance selection index model. *Journal of Achievements in Materials and Manufacturing Engineering*. https://doi.org/10.5604/01.3001.0010.2077

Kant, P., & Gupta, S. (2022). Key Performance Indicators of Sustainable Urban Freight for Jaipur City in India. In *Lecture notes in civil engineering* (pp. 315–328). Springer, Singapore. https://doi.org/10.1007/978-981-16-9925-2_22

Kaplan, R. C., & Norton, D. P. (1997). The balanced scorecard: Translating strategy into action. *Long Range Planning*, *30*(3), 467. https://doi.org/10.1016/s0024-6301(97)80925-9

Keim, D. A., Mansmann, F., & Thomas, J. A. (2010). Visual analytics. *SIGKDD Explorations*, *11*(2), 5–8. https://doi.org/10.1145/1809400.1809403

Kotter, J. P. (1996). Why Transformation Efforts Fail. *Journal of Product Innovation Management*, *2*(13), 170.

Kusrini, E., Safitri, K. N., & Fole, A. (Eds.). (2019). *Design Key Performance Indicator for Distribution Sustainable Supply Chain Management*. https://doi.org/10.1109/DASA51403.2020.9317289

Lebanon, G., & El-Geish, M. (2018). *Computing with Data: An Introduction to the Data Industry*. Springer.

Linstone, H. A., & Turoff, M. (1975). *The Delphi Method: Techniques and Applications*. Westview Press.

Liu, P., & Tsai, C. (2007). Using Analytic Network Process to establish performance evaluation indicators for the R&D Management department in Taiwan's high-tech industry. *Asian Journal on Quality*, *8*(3), 156–172. https://doi.org/10.1108/15982688200700030

Locke, E. A., & Latham, G. P. (2013). New Developments in Goal Setting and Task Performance. *Routledge eBooks*. https://doi.org/10.4324/9780203082744

Marr, B. (2012). *Key Performance Indicators: The 75 Measures Every Manager Needs to Know*. Financial Times/Prentice Hall.

Meignan, D., Knust, S., Frayret, J., Pesant, G., & Gaud, N. (2015). A Review and Taxonomy of Interactive Optimization Methods in Operations research. *ACM Transactions on Interactive Intelligent Systems*, *5*(3), 1–43. https://doi.org/10.1145/2808234

Mento, A. J., Jones, R. C. F., & Dirndorfer, W. (2002). A change management process: Grounded in both theory and practice. *Journal of Change Management*, *3*(1), 45–59. https://doi.org/10.1080/714042520

Moktadir, M. A., Mahmud, Y., Banaitis, A., Sarder, T., & Khan, M. R. (2021). Key Performance Indicators for Adopting Sustainability Practices in Footwear Supply Chains. *E+M. Ekonomie a Management*, *24*(1), 197–213. https://doi.org/10.15240/tul/001/2021-1-013

Molina-Carmona, R., Llorens Largo, F., & Fernández Martínez, A. (2018, June 1). *Data-driven indicator classification and selection for dynamic dashboards: The case of Spanish universities*. Retrieved April 6, 2023, from http://hdl.handle.net/10045/86991

Moore, J. (2017). Data Visualization in Support of Executive Decision Making. *Interdisciplinary Journal of Information, Knowledge, and Management*, *12*, 125–138. https://doi.org/10.28945/3687

Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence-Based Nursing*, *18*(2), 34–35. https://doi.org/10.1136/eb-2015-102054

Nelissen, P., & Van Selm, M. (2008). Surviving organizational change: how management communication helps balance mixed feelings. *Corporate Communications: An International Journal*, *13*(3). https://doi.org/10.1108/13563280810893670

Parmenter, D. (2019). *Key Performance Indicators: Developing, Implementing, and Using Winning KPIs*. John Wiley & Sons.

Pastushenko, O., Hynek, J., & Hruška, T. (2019). Evaluation of user interface design metrics by generating realistic-looking dashboard samples. *Expert Systems*, *38*(5). https://doi.org/10.1111/exsy.12434

Pauwels, K., Ambler, T., Clark, B. H., LaPointe, P., Reibstein, D., Skiera, B., Wierenga, B., & Wiesel, T. (2009). Dashboards as a Service : Why, What, How, and What Research Is Needed? *Journal of Service Research*, *12*(2), 175–189. https://doi.org/10.1177/1094670509344213

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/mis0742-1222240302

Pietersen, W. (2002). THE MARK TWAIN DILEMMA: THE THEORY AND PRACTICE OF CHANGE LEADERSHIP. *Journal of Business Strategy*, *23*(5), 32–37. https://doi.org/10.1108/eb040272

Pokhrel, S. R., Chhipi-Shrestha, G., Hewage, K., & Sadiq, R. (2023). Key performance indicators for small and medium-sized urban water systems in a semi-arid region: a case study of Okanagan Valley, Canada. *Urban Water Journal*, *20*(4), 435–449. https://doi.org/10.1080/1573062x.2023.2179927

Polit, D. F., & Beck, C. T. (2010). Generalization in quantitative and qualitative research: Myths and strategies. *International Journal of Nursing Studies*, *47*(11), 1451–1458. https://doi.org/10.1016/j.ijnurstu.2010.06.004

Powell, C. E. (2003). The Delphi technique: myths and realities. *Journal of Advanced Nursing*, *41*(4), 376–382. https://doi.org/10.1046/j.1365-2648.2003.02537.x

Rodrigues, D., Godina, R., & Cruz, P. (2021). Key Performance Indicators Selection through an Analytic Network Process Model for Tooling and Die Industry. *Sustainability*, *13*(24), 13777. https://doi.org/10.3390/su132413777

Roopa, S., & Rani. (2012). Survey designing for a survey. *The Journal of Indian Orthodontic Society*, *46*, 273–277. https://doi.org/10.5005/jp-journals-10021-1104

Saaty, T. L. (1988). What is the Analytic Hierarchy Process? In *Springer eBooks* (pp. 109–121). https://doi.org/10.1007/978-3-642-83555-1_5

Salgado, T. M., Reynolds, T. P., Frankart, L. M., Holdford, D. A., & DiPiro, J. T. (2020). A key performance indicators redefinition initiative at a school of pharmacy using a modified Delphi consensus technique. *Pharmacy Practice (Internet)*, *18*(4), 2120. https://doi.org/10.18549/pharmpract.2020.4.2120

Sarialioglu, B. (2014). *Software Testing Tips: Experiences & Realities*. Baris Sarialioglu.

Schroeder, R. G., Linderman, K., Liedtke, C., & Choo, A. S. (2007). Six Sigma: Definition and underlying theory⋆. *Journal of Operations Management*, *26*(4), 536–554. https://doi.org/10.1016/j.jom.2007.06.007

Seker, S., & Zavadskas, E. K. (2017). Application of Fuzzy DEMATEL method for analyzing occupational risks on construction sites. *Sustainability*, *9*(11), 2083. https://doi.org/10.3390/su9112083

Shahin, A., & Mahbod, M. A. (2007). Prioritization of key performance indicators. *International Journal of Productivity and Performance Management*, *56*(3), 226–240. https://doi.org/10.1108/17410400710731437

Sharma, V., Cassetti, O., Winning, L., O'Sullivan, M., & Crowe, M. (2023). Protocol for developing a dashboard for interactive cohort analysis of oral health-related data. *BMC Oral Health*, *23*(1). https://doi.org/10.1186/s12903-023-02895-2

Shneiderman, B. (1996). The eyes have it: a task by data type taxonomy for information visualizations. In *IEEE Symposium on Visual Languages*. https://doi.org/10.1109/vl.1996.545307

Smith, M. (2003, September 20). *Dashboards or Scorecards - What's the Difference?* ventanaresearch.com. Retrieved April 5, 2023, from http://issel.co.uk/wp-content/uploads/2017/07/dash_score_differences.pdf

Snyder, H. R. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Solomon, D. (2007). The role of peer review for scholarly journals in the Information Age. *Journal of Electronic Publishing*, *10*(1). https://doi.org/10.3998/3336451.0010.107

Spackman, E., Clement, F., Allan, G. M., Bell, C. M., Bjerre, L. M., Blackburn, D., Blais, R., Hazlewood, G., Klarenbach, S., Nicolle, L. E., Persaud, N., Alessi-Severini, S., Tierney, M., Wijeysundera, H. C., & Manns, B. J. (2019). Developing key performance indicators for prescription medication systems. *PLOS ONE*. https://doi.org/10.1371/journal.pone.0210794

Stenbacka, C. (2001). Qualitative research requires quality concepts of its own. *Management Decision*, *39*(7), 551–556. https://doi.org/10.1108/eum0000000005801

Stoltzman, S. (2018). Data Visualization – Part 3. *Open Data Science - Your News Source for AI, Machine Learning & More*. https://opendatascience.com/data-visualization-part-3/

Stouten, J., Rousseau, D. M., & De Cremer, D. (2018). Successful Organizational Change: Integrating the Management Practice and Scholarly Literatures. *The Academy of Management Annals*, *12*(2), 752–788. https://doi.org/10.5465/annals.2016.0095

Strugar, D. (2020). Recommender systems: metric suggestion mechanisms applied to adaptable software dashboards. *Foundations of Software Engineering*. https://doi.org/10.1145/3368089.3418779

Sundqvist, E., Bäcklund, F., & Chronéer, D. (2014). What is Project Efficiency and Effectiveness? *Procedia - Social and Behavioral Sciences*, *119*, 278–287. https://doi.org/10.1016/j.sbspro.2014.03.032

Taherdoost, H. (2022). How to Conduct an Effective Interview; A Guide to Interview Design in Research Study Authors. *International Journal of Academic Research in Management*, *11*(1), 39–51.

Van De Weert, M., & Stella, L. (2019). The dangers of citing papers you did not read or understand. *Journal of Molecular Structure*, *1186*, 102–103. https://doi.org/10.1016/j.molstruc.2019.03.024

Vilarinho, S. F. S., Lopes, I., & Sousa, S. F. (2017). Design Procedure to Develop Dashboards Aimed at Improving the Performance of Productive Equipment and Processes. *Procedia Manufacturing*, *11*, 1634–1641. https://doi.org/10.1016/j.promfg.2017.07.314

Vilarinho, S. F. S., Lopes, I., & Sousa, S. F. (2018). Developing dashboards for SMEs to improve performance of productive equipment and processes. *Journal of Industrial Information Integration*, *12*, 13–22. https://doi.org/10.1016/j.jii.2018.02.003

Womack, J. P., & Jones, D. M. (1997). Lean Thinking—Banish Waste and Create Wealth in your Corporation. *Journal of the Operational Research Society*, *48*(11), 1148. https://doi.org/10.1038/sj.jors.2600967

Yanine, F., Córdova, F. M., & Durán, C. A. (2020). The Impact of Dynamic Balanced Scorecard in Knowledge-Intensive Organizations' Business Process Management: A New Approach Evidenced by Small and Medium-Size Enterprises in Latin America. *Journal of Information Technology Management*, *12*(2), 131–152. https://doi.org/10.22059/jitm.2020.75797

Yigitbasioglu, O., & Velcu, O. (2012). A review of dashboards in performance management: Implications for design and research. *International Journal of Accounting Information Systems*, *13*(1), 41–59. https://doi.org/10.1016/j.accinf.2011.08.002

Zelazny, G. (2001). *Say It With Charts: The Executive's Guide to Visual Communication* (4th ed.). McGraw Hill Professional. https://doi.org/10.1036/007136997X

Zhou, B., Liang, S., Monahan, K. M., Singh, G. M., Simpson, R. B., Reedy, J., Zhang, J., DeVane, A., Cruz, M. R., Marshak, A., Mozaffarian, D., Wang, D., Semenova, I. A., Roura, I. M., Prozorovscaia, D., & Naumova, E. N. (2022). Food and Nutrition Systems Dashboards: A Systematic review. *Advances in Nutrition*, *13*(3), 748–757. https://doi.org/10.1093/advances/nmac022

Appendix A ‘Survey Initial Value Objectives’

This appendix shows the text and statements as shown in the survey to measure the initial value of the objectives.

‘The purpose of this survey is to measure the effectiveness and efficiency with which employees gather insights into the bottlenecks of the tape drive test process. With ‘bottlenecks’ we mean the part of the process with the lowest capacity. We would like to hear your opinion about the way Bluetron currently handles data regarding the tape drive test process. A difference that is of great importance to this survey is the difference between data and information. With ‘data’, we mean raw facts and with ‘information’ we mean structured data that is put in context.

This research is anonymous and we will make sure that the data cannot be traced back to you as employee. Moreover, you are always free to withdraw from the research. If you feel that you have not enough knowledge or information to answer a question, you can skip it.

Thank you in advance for filling in the survey.’

Statement 1.

‘Enough data is generated during the tape drive test process to be able to gather insight into the bottlenecks of the process.’

Statement 2.

‘The generated data is transferred to clearly interpretable information about the tape drive test process.’

Statement 3.

‘The generated data is transferred to clearly interpretable information which gives a complete insight into the bottlenecks of the tape drive test process.’

Statement 4.

‘I need the minimal amount of time to acquire clearly interpretable information which gives insight into the bottlenecks of the tape drive test process.’

If you have any questions about one of the statements, please contact us.

Appendix B ‘SLR KPI Selection Methods’

This appendix discusses the systematic literature review we performed to discover relevant methods of KPI selection. The systematic literature review consists of a search strategy, a selection, and an integration of theory. This appendix discusses the search strategy and the selection and Section 3.1 ‘KPI Selection Methods’ discusses the integration of the theory. In this Appendix, Section A.1 discusses the search strategy in terms of the knowledge problem, the search terms, academic databases, and a search log. Section A.2 explains the selection of articles with regard to in- and exclusion criteria and a screening strategy.

B.1 Search Strategy

The problem is that we do not know yet how to select the most relevant KPIs out of a range of alternative KPIs. The question we want to answer with this systematic literature review is the following:

‘What are relevant methods to select KPIs for a dashboard design for Bluetron?’

The key concepts of the search strategy are ‘method’, ‘KPI’, and ‘selection’. Table 6 shows the key concepts and their related, narrower, and broader terms.

Table 9 Key concepts KPI selection methods

Key concepts		Related terms	Narrower terms	Broader terms
1	**Method**	Procedure	-	Approach
2	**KPI**	Key performance indicator	-	Performance indicator
3	**Selection**	Choice, Identification	-	Assessment

For this literature review, we will use two databases, namely Scopus and ScienceDirect. We use these databases, because they are multidisciplinary and they are offered by the University of Twente.

Important factors to take into consideration when determining which database(s) to use for a literature review are the topic area of the question, type of information required, the functionality of the search platform, and access possibilities of different databases (Levay & Craven, 2019). For this review, we need academic papers about KPI selection which we can search for with Boolean operators and we want to be able to access all papers within the chosen database. KPI selection is dealt with in many fields of research, and therefore it is beneficial to use multidisciplinary databases to make the search as complete as possible. Due to accessibility of databases, we will use databases offered by the University of Twente.

Based on these criteria, we will use two multidisciplinary databases, namely Scopus and ScienceDirect. Scopus is a database that covers a variety of disciplines and allows for many Boolean operators to be used (Elsevier, n.d.). Therefore, Scopus is a suitable database for this literature review. ScienceDirect is a database that offers a large collection of Physical Sciences and Engineering publications and this database also allows Boolean operators in search strings (*Science, health and medical journals, full text articles and books,* n.d.). ScienceDirect is thus also a suitable database for this literature search. We specifically choose not to include a topic-specific database, since KPI selection is used in many different disciplines.

Table 7 shows the search terms used and the way they were structured for Scopus and ScienceDirect to carry out an accurate and complete search. The first column shows the search query we used, the second column shows the database in which we searched, the third column shows the number of hits the search produced, and the fourth column shows remarks about the search. The two green rows are the final searches for this systematic literature review.

Table 10 Search log KPI selection methods

Search query	Database	Hits	Remarks
Method AND KPI AND Selection	Scopus	118	Fine search, some hits, but not as much as wanted. 'KPI' and 'selection' need to be closer to each other.
Method AND KPI PRE/3 Selection	Scopus	15	The articles that are in this search are mostly good articles, but the search is too narrow.
Method AND (KPI* OR "key performance indicator") PRE/3 selection	Scopus	27	Articles involved in the search are good articles. The search is less narrow than the previous search, but still too narrow.
(Method OR Approach) AND (KPI* OR "key performance indicator") PRE/3 selection	Scopus	46	Articles involved in the search are good articles. The search is less narrow than the previous search, but still too narrow.
(Method OR Approach) AND (KPI* OR "key performance indicator") PRE/3 (selection OR identification)	Scopus	67	Articles involved in the search are good articles. The search is less narrow than the previous search, but still too narrow
(Method* OR approach) AND (KPI* OR "key performance indicator") PRE/1 (select* OR identif*) with search filter 'search within abstract'	Scopus	195	The articles involved are mostly good articles and the search is broad enough.
(Method OR approach) AND (KPI OR "key performance indicator") AND (selection OR identification) + filter 'decision sciences'	ScienceDirect	1834	Not a very good search. Too broad and many unnecessary articles.
(Method OR Approach) AND ("kpi selection" OR "key performance indicator selection")	ScienceDirect	83	Good search. KPI selection is the main topic of most papers, however, search is a little too narrow.
(Method OR Approach) AND ("kpi selection" OR "key performance indicator selection" OR "kpi identification)	ScienceDirect	109	Good search. KPI selection is the main topic of most papers, however search is a little too narrow.
(Method OR Approach) AND ("kpi selection" OR "key performance indicator selection" OR "kpi identification" OR "key performance indicator identification")	ScienceDirect	118	Good search. Most articles cover KPI selection and the search is broad enough to be used.

B.2 Selection

Table 8 shows the in- and exclusion criteria for this systematic literature review. Column 1 shows the inclusion criteria, so the criteria to which a paper has to comply in order to be included in the review. Column 2 shows the justification for the choice of these inclusion criteria. Column 3 shows the exclusion criteria, the criteria for a paper to be excluded from the review, and column 4 shows the justification for these criteria.

Table 11 In- and exclusion criteria KPI selection methods

Inclusion criteria	Justification	Exclusion criteria	Justification
Full-text access	Proper citation of papers can only be done once an article is read and understood (van de Weert & Stella, 2019). Therefore, to include the paper in the review, it has to be read to interpret the paper properly.	Non-peer-reviewed journals	Peer review is based on the assumption that it provides a valid measure of quality and adherence to the norms of the field. Non-peer-reviewed journals are more likely to contain errors (Solomon, 2007), and therefore these journals will be excluded from this research
The emphasis of the study has to be on KPI selection	The literature review is about methods to select KPIs. To write an accurate review, the papers included have to extensively talk about KPI selection.	Studies that address the selection of already-known KPIs	For this research, we do not have a list of KPIs yet. Therefore papers that use existing lists of KPIs do not apply to this research.

Table 9 and table 10 show the final searches in Scopus and ScienceDirect. We have filtered the papers based on title, abstract, and complete reading.

Table 12 Scopus included articles KPI selection methods

Source	Scopus
Total number of hits	195
Selecting based on the title	- 134
Selecting based on abstract	-32
Removed after a complete reading	-24
Added (forward/backward referencing)	+11
Total for review	**16**

Table 13 ScienceDirect included articles KPI selection methods

Source	ScienceDirect
Total number of hits	119
Selecting based on the title	- 82
Selecting based on abstract	-26
Removed after a complete reading	-8

Added (forward/backward referencing)	+6
Total for review	**9**

Table 10 shows the articles included in this literature review together with the concept, the focus, and the purpose of the paper.

Concept														
Author(s)	*KPIs*	*Literature*	*Expert opinion*	*Delphi*	*PROMETHEE*	*AHP*	*SMART goal setting*	*Fuzzy AHP*	*ANP*	*DEMATEL*	*BWM*	*ELECTRE*	*ISM*	**Focus**	**Purpose**
Armstrong, 2017	X													KPIs	Explanation
Cai et al., 2009	X													KPIs	Explanation
Marr, 2012	X		X											Expert Opinion	Explanation
Dwivedi & Madaan, 2020	X	X	X											Expert Opinion	Case Study
Spackman et al., 2019	X	X	X											Expert Opinion	Case Study
Ho, Lai & Chiu, 2021	X	X	X											Expert Opinion	Case Study
Barber et al., 2020	X	X	X	X										Delphi	Case Study
Salgado et al., 2020	X			X										Delphi	Case Study
Pokhrel et al., 2023	X			X	X									Delphi	Case Study
Saaty, 1988						X								AHP	Explanation
Anjomshoae, Hassan & Wong, 2019	X					X								AHP	Case Study
Kusrini , Safitri & Fole, 2020	X	X				X								AHP	Case Study
Kant & Gupta, 2022	X	X				X								AHP	Case Study
Shahin & Mahbod, 2007	X					X	X							AHP + SMART	Case study
Gözaçan & Lafci, 2020	X	X				X	X							AHP + SMART	Case Study
Kaganski & Toompalu, 2017	X		X					X						Fuzzy AHP	Case Study
Ganguly & Rai, 2018	X	X						X						Fuzzy AHP	Case Study
Liu & Tsai, 2007									X					ANP	Explanation
Carlucci, 2010	X								X					ANP	Explanation
Rodrigues, Godina & Cruz, 2021	X	X							X					ANP	Case Study
Seker & Zavadskas, 2017										X				DEMATEL	Explanation
Bapat, Sarkar & Gujar, 2022	X	X								X				DEMATEL	Case Study
Moktadir et al., 2021	X	X									X			BWM	Case Study
Gonçalves, Dias, & Machado, 2015	X											X		ELECTRE	Case Study
Amrina & Yulianto, 2018	X	X	X										X	ISM	Case Study

Appendix C ‘SLR KPI Visualization Choices’

This appendix discusses the systematic literature review we performed to gain knowledge about the criteria for choosing relevant visual representations. The systematic literature review consists of a search strategy, a selection, and an integration of theory. This appendix discusses the search strategy and the selection and Section 3.2 ‘KPI Visualization Choices’ discusses the integration of the theory. In this Appendix, Section A.1 discusses the search strategy in terms of the knowledge problem, the search terms, academic databases, and a search log. Section A.2 explains the selection of articles with regard to in- and exclusion criteria and a screening strategy.

C.1 Search Strategy

We want to design a dashboard displaying the most relevant KPIs for Bluetron. We already identified a method for selecting the most relevant KPIs out of a series of alternatives. The next step is to choose visual representations for these KPIs. The problem is that we do not know yet the criteria for choosing relevant visual representations for the selected KPIs. The question we want to answer with this systematic literature review is the following:

‘What are the criteria for choosing relevant visual representations for dashboards?’

The key concepts of the search strategy are ‘KPI, ‘Visual representation’, and ‘Dashboard’. Table 11 shows the key concepts and their related, narrower, and broader terms.

Table 14 Key concepts KPI visualization choices

Key concepts		Related terms	Narrower terms	Broader terms
1	**KPI**	Key Performance Indicator	-	Performance indicator
2	**Visual representation**	Visualization	Display	-
3	**Dashboard**	-	KPI dashboard	Instrument panel

For this literature review, we will use two databases, namely Scopus and ScienceDirect. We use these databases, because they are multidisciplinary and they are offered by the University of Twente.

Table 12 shows the search terms used and the way they were structured for Scopus and ScienceDirect to carry out an accurate and complete search. The first column shows the search query we used, the second column shows the database in which we searched, the third column shows the number of hits the search produced, and the fourth column shows remarks about the search. The two green rows are the final searches for this systematic literature review.

Table 15 Search log KPI visualization choices

Search query	Database	Hits	Remarks
“KPI visualization” AND dashboard	Scopus	1	Bad search. Too narrow
KPI PRE/3 visualization AND dashboard	Scopus	4	Bad search. Too narrow
“KPI visualization”	Scopus	10	Some good results, but not a good search
KPI PRE/3 visualization	Scopus	19	Some good hits, but not enough

KPI AND “Visual representations”	Scopus	2	Bad search. Too narrow.
KPI* AND visual* AND represent*	Scopus	49	Medium good search. Some good hits, but some of the terms have to be closer to each other.
KPI* AND visual* PRE/3 represent*	Scopus	9	Too narrow again
KPI* AND represent*	Scopus	785	Too broad. Representation is either not a good word or it has to be closer to KPI*
KPI PRE/2 Represent*	Scopus	60	Not a good search. Represent* does not cover the topic we need.
KPI PRE/2 Visual*	Scopus	32	Relatively good search. Some good papers. Visual* is better than represent*.
(KPI* OR “key performance indicator”) PRE/2 visual*	Scopus	42	Better search than the previous search. Need to explore more synonyms
(KPI* OR “key performance indicator”) PRE/2 (visual* OR display*)	Scopus	65	Display* adds some extra hits. The focus with display is already more on dashboard
(KPI OR KPIs OR "key performance indicators" OR "key performance indicator") AND (visual OR visualization OR display)	ScienceDirect	12.523	Way too broad. I need to specify the search more.
(KPI OR KPIs OR "key performance indicators" OR "key performance indicator") AND visualization	ScienceDirect	6.557	Better search than the previous search, but still too many hits.
“KPI visualization”	ScienceDirect	21	Very good search. Almost all articles are relevant. Try to make it a little bit broader still.
“KPI visualization” OR “Key performance indicator visualization”	ScienceDirect	26	Good search. A lot of relevant articles
“KPI visualization” OR “Key performance indicator visualization” OR “KPI display”	ScienceDirect	42	Good search. “KPI display” adds relevant articles on dashboards.

C.2 Selection

Table 13 shows the in- and exclusion criteria for this systematic literature review. Column 1 shows the inclusion criteria, so the criteria to which a paper has to comply in order to be included in the review. Column 2 shows the justification for the choice of these inclusion criteria. Column 3 shows the exclusion criteria, the criteria for a paper to be excluded from the review, and column 4 shows the justification for these criteria.

Table 16 In- and exclusion criteria KPI visualization choices

Inclusion criteria	Justification	Exclusion criteria	Justification
Full-text access	Proper citation of papers can only be done once an article is read and understood (van de Weert & Stella, 2019). Therefore, to include the paper in the review, it has to be read to interpret the paper properly.	Non-peer-reviewed journals	Peer review is based on the assumption that it provides a valid measure of quality and adherence to the norms of the field. Non-peer-reviewed journals are more likely to contain errors (Solomon, 2007), and therefore these journals will be excluded from this research
Main focus of the paper on visualizations	The main focus of the paper has to be on visual representations and their criteria for usage.	No emphasis on KPI visualizations	In this research, we want to visualize KPIs with suitable visual representations. The focus of the paper will thus have to lie on visualizations for KPIs and if that is not the case, we will not use the paper.

Table 14 and Table 15 show the final searches in Scopus and ScienceDirect. We have filtered the papers based on title, abstract, and complete reading.

Table 17 Scopus included articles KPI visualization choices

Source	Scopus
Total number of hits	65
Selecting based on the title	-55
Selecting based on abstract	-2
Removed after a complete reading	-7
Added (forward/backward referencing)	+2
Total for review	**3**

Table 18 ScienceDirect included articles KPI visualization choices

Source	ScienceDirect
Total number of hits	42
Selecting based on the title	-37
Selecting based on abstract	-0
Removed after a complete reading	-3
Added (forward/backward referencing)	+3
Total for review	**5**

Table 16 shows the articles included in this literature review together with the focus of the paper.

Table 19 Conceptual Matrix KPI visualization choices

Author(s)	Focus
Keim, Mansmann & Thomas, 2010	Visual Analytics

Marr, 2003	Visual representations
Moore, 2017	Data visualization
Zelazny, 2001	Choosing suitable chart forms
Stoltzman, 2018	Purposes for visual representations
Lebanon & El-Geish, 2018	Plot types
Shneidermann, 1996	Data types
Halim & Tufail, 2017	Metrics for determining suitability of visualization

Appendix D 'SMART Analytic Hierarchy Process'

This appendix discusses the SMART Analytic Hierarchy Process as described by Shahin and Mahbod (2007) in their research.

The first step, defining and listing all of the KPIs, has already been executed in the previous sections, namely in the sections 4.1.1 'KPIs in literature', 4.1.2 'Expert Opinion KPIs', and 4.1.3 'Company KPIs'. The second step is to build an AHP hierarchy based on SMART characteristics. The AHP hierarchy consists of three levels; the focus, the criteria, and the alternatives (Saaty, 1988). Figure 29 shows the AHP hierarchy composed by Shahin and Mahbod (2007). The AHP hierarchy for this thesis is very similar to the one in Figure 29. The focus is on selecting KPIs for a dashboard that supports decision making in the field of bottlenecks in the tape drive test process. The criteria are based on SMART; Specific, Measurable, Attainable, Realistic, and Timely. Lastly, the alternatives are the KPIs defined and listed in the previous sections.

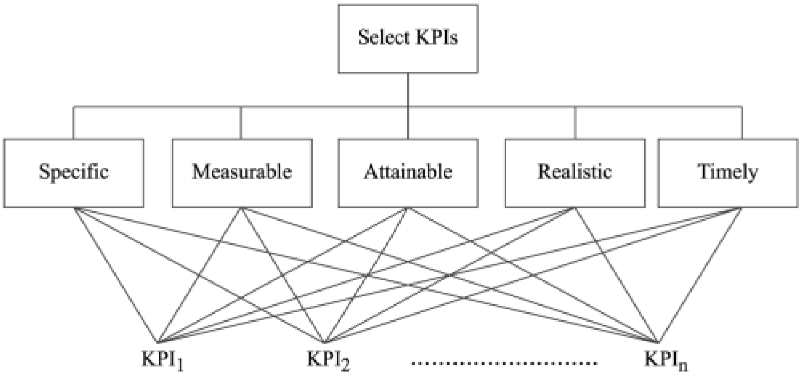


Figure 22 Hierarchical structure (Shahin & Mahbod, 2007)

Step 3 of the SMART AHP approach is called 'pairwise comparison'. In this step, a pairwise comparison matrix is set up together with the stakeholders of the process. As Shahin and Mahbod (2007) explain in their research, in pairwise comparison, two criteria are compared with each other using a scale of relative importance. Figure 30 shows this scale of relative importance. Say A is the pairwise comparison matrix with the SMART criteria. This matrix A contains of the entries a_{ij}, where i is in between 1 and 5 and j is also between 1 and 5. The entry a_{ij} denotes the importance of the i^{th} (left) element with respect to the j^{th} (top) element. Moreover, the entry a_{ji} is calculated by $\frac{1}{a_{ij}}$, which is called the inverse.

Ratings	Definition	Intensity of importance
1	Equal importance	Two criteria/alternatives contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgement slightly favour one criterion/alternative over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one criterion/alternative over another
6	Strong plus	
7	Very strong importance	A criterion/alternative is favoured very strong over another
8	Very, very strong	
9	Extreme importance	The evidence favouring one criterion/alternative over another is of the highest possible order of affirmation

Figure 23 Pairwise comparison score scale (Shahin & Mahbod, 2007)

The values of the pairwise comparison matrix are based on human intuition (Xia & Wu, 2007) and therefore we determined these values during a focus group with 4 employees of Bluetron who are all different stakeholders of the tape drive test process. The emphasis of this focus group lay on the different opinions of these stakeholders, as they are the decision makers. Table 17 shows the pairwise comparison matrix with criteria Specific, Measurable, Attainable, Realistic, and Timely, that was composed during the focus group.

Table 20 Pairwise Comparison Matrix A

	S	M	A	R	T
S	1	3	2	3	2
M	1 / 3	1	1 / 3	1	1 / 3
A	1 / 2	3	1	2	1
R	1 / 3	1	1 / 2	1	1 /3
T	1 / 2	3	1	3	1

As part of the pairwise comparison step, we calculate a normalized matrix, say matrix B, based on the pairwise comparison matrix. The entry b_{ij} of the normalized matrix B is calculated by $\frac{a_{ij}}{\sum_{j=1}^{5} a_{ij}}$. Table 18 shows this normalized matrix B which is based on the pairwise comparison matrix shown in Table 17.

Table 21 Normalized Matrix B

	S	M	A	R	T
S	3 / 8	3 / 11	12 / 29	3 / 10	3 / 7
M	1 / 8	1 / 11	2 / 29	1 / 10	1 / 14
A	1 / 16	3 / 11	6 / 29	1 / 5	3 / 14
R	1 / 8	1 / 11	3 / 29	1 / 10	1 / 14
T	3 / 16	3 / 11	6 / 29	3 / 10	3 / 14

The next step of the approach is to calculate the relative importance weights of the SMART criteria based on the two matrices A and B. This is done by calculating a column vector C containing 5 rows where every entry c_i stands for the weight for criteria number i. The entries c_i are calculated as follows: $c_i = \frac{\sum_{j=1}^{5} a_{ij}}{5}$. Table 19 shows the column vector C and thus the weights of the SMART criteria.

Table 22 Column Vector C Criteria weights

Criteria	Weight
S	0.36
M	0.09
A	0.22
R	0.10
T	0.24

A step that is not mentioned in the AHP approach by Shahin and Mahbod is the consistency check. This step calculates the consistency ratio (CR) of the pairwise comparison matrix A to ensure that the judgments of decision makers are consistent (Saaty, 1988). A CR of 0.1 or less is considered acceptable by Saaty (1988). The consistency ratio is calculated by dividing the consistency index (CI) by the random index (RI). The RI is based on the size of the matrix. Figure 31 shows the random indexes for different matrix sizes. For this thesis, the size of the matrix is 5x5 and therefore a RI of 1.12 will be utilized

Matrix	1	2	3	4	5	6	7	8	9	10	11	12
IR	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Figure 24 Random Index (Saaty, 1988)

The consistency index can be found by the following equation: CI = $\frac{\lambda_{max}-5}{5-1}$, where λ_{max} is the largest eigenvalue of the pairwise comparison matrix. To calculate this eigenvalue, a new matrix is created, D, where the entries d_{ij} are calculated by multiplying the entry of the pairwise comparison matrix, a_{ij}, with the accompanying weight c_j. Table 20 shows the matrix D, calculated from the criteria weights and the pairwise comparison matrix.

Table 23 Matrix D

	S	M	A	R	T
S	0.36	0.27	0.43	0.29	0.47
M	0.12	0.09	0.07	0.10	0.08
A	0.18	0.27	0.22	0.20	0.24
R	0.12	0.09	0.11	0.10	0.08
T	0.18	0.27	0.22	0.29	0.24

The next step is to calculate the weighted sum value of each row in a column vector E. This column vector has entries e_i and these entries are calculated by $e_i = \frac{\sum_{j=1}^{5} d_{ij}}{c_i}$. Table 21 shows this column vector E.

Table 24 Column Vector E

Criteria	Weighted Sum Value
S	5.12
M	5.04
A	5.09
R	5.05
T	5.08

Now, λ_{max} can be calculated using the following calculation: $\frac{\sum_{i=1}^{5} e_i}{5}$. These calculations deliver a λ_{max} of 5.07. This yields a consistency index of 0.02, which in turn yields a consistency ratio of 0.017. As the requirement for the consistency ratio to be lower than 0.1 is followed, the decision makers' judgement is determined to be consistent (Saaty, 1988).

The last step of the approach by Shahin and Mahbod (2007) consists of selecting the relevant KPIs using the determined criteria weights. We will do this by scoring the identified KPIs on a scale from 1 to 5. Table 22 shows the meaning of these numbers.

Table 25 KPI Scoring

1	2	3	4	5
Bad	**Poor**	**Neutral**	**Acceptable**	**Good**

The four employees that participated in the focus group have assigned scores for the criteria to the 22 identified KPIs. We calculated the average of these 4 scores to ensure equality of the opinions of the different stakeholders. The final scores for the KPIs are calculated by multiplying the score for a certain criteria with the weight of that criteria. The KPI 'NDF Fail', for example, is calculated as follows:

$$3 * 0.36 + 5 * 0.09 + 4 * 0.22 + 4 * 0.10 + 4 * 0.24 = 3.73$$

Appendix E 'SLR Dashboard Design Guidelines'

This appendix discusses the systematic literature review we performed to gain knowledge about the design of dashboards. The systematic literature review consists of a search strategy, a selection, and an integration of theory. This appendix discusses the search strategy and the selection and Section 5.1 'Literature Dashboard Design' discusses the integration of the theory. In this Appendix, Section ?.1 discusses the search strategy in terms of the knowledge problem, the search terms, academic databases, and a search log. Section ?.2 explains the selection of articles with regard to in- and exclusion criteria and the screening strategy.

E.1 Search Strategy

We want to design a dashboard displaying the most relevant KPIs for Bluetron. We already selected relevant KPIs for the dashboard and their visual representations. The next step is to put these KPIs together in a dashboard view. The problem is that we do not know yet how to design such a dashboard view. The question we want to answer with this systematic literature review is the following:

'What are guidelines for designing a dashboard that gives insight into performance KPIs?'

The key concepts of the search strategy are 'Dashboard, 'Design', and 'Guidelines' Table 23 shows the key concepts and their related, narrower, and broader terms.

Table 26 Key concepts Dashboard design guidelines

Key concepts		Related terms	Narrower terms	Broader terms
1	**Dashboard**	-	-	Instrument panel
2	**Design**	Creation	Features, Functional features, Design features, Interactive	-
3	**Guidelines**	Rules, Theoretical framework		-

For this literature review, we will use two databases, namely Scopus and ScienceDirect. We use these databases, because they are multidisciplinary and they are offered by the University of Twente.

Table 24 shows the search terms used and the way they were structured for Scopus and ScienceDirect to carry out an accurate and complete search. The first column shows the database we used, the second column shows the search query, the third column shows the number of hits the search produced, and the fourth column shows remarks about the search. The three green rows are the final searches for this systematic literature review.

Table 27 Search log Dashboard design guidelines

Database	Search Query	Hits	Remarks
ScienceDirect	"dashboard design"	225	The search is too vague, the topics of the papers deviate

			too much from dashboard design
ScienceDirect	creation AND dashboard	5793	Way too broad.
ScienceDirect	creation AND dashboard AND visualization	2795	Still way too broad.
ScienceDirect	creation AND dashboard AND guidelines	2118	Still not a very good search. Many papers that are off-topic.
ScienceDirect	Guidelines AND dashboard AND design	5234	The search in ScienceDirect is not going well. I am switching to Scopus to see whether this search gets better results.
Scopus	dashboard AND design AND guidelines	152	Good search.
Scopus	dashboard AND (design OR creation) AND guidelines	165	An even better search. This search will be utilized for the SLR.
ScienceDirect	Dashboard AND Features	10377	Way too broad, I have to make the search more narrow to find the information I need.
ScienceDirect	"Interactive Dashboarding"	470	Fine search, however still too many papers that do not refer to the topic I am looking for.
ScienceDirect	"Interactive dashboarding" AND "Functional features"	3	No good search results for this search.
ScienceDirect	Dashboard AND "Functional features"	87	Good search. Most of the articles talk about the design of dashboards.
Scopus	Dashboard AND "Functional features"	2	No search results for the information we need.
Scopus	Dashboard AND interactiv*	1264	Fine search, the topic seems to be fine, but still a bit too broad. Will try to make the search more narrow
Scopus	Dashboard AND interactivity	48	Much better search. The focus of the papers is good. Will use this search.

E.2 Selection

Table 25 shows the in- and exclusion criteria for this systematic literature review. Column 1 shows the inclusion criteria, so the criteria to which a paper has to comply in order to be included in the review. Column 2 shows the justification for the choice of these inclusion criteria. Column 3 shows the exclusion criteria, the criteria for a paper to be excluded from the review, and column 4 shows the justification for these criteria.

Table 28 In- and exclusion criteria Dashboard design guidelines

Inclusion criteria	Justification	Exclusion criteria	Justification
Full-text access	Proper citation of papers can only be done once an article is read and understood (van de Weert & Stella, 2019). Therefore, to include the paper in the review, it has to be read to interpret the paper properly.	Non-peer-reviewed journals	Peer review is based on the assumption that it provides a valid measure of quality and adherence to the norms of the field. Non-peer-reviewed journals are more likely to contain errors (Solomon, 2007), and therefore these journals will be excluded from this research
Focus on the design of dashboards	The articles have to focus on the design of dashboards, in terms of design and functional features.	Focus on the technical creation of dashboards	Since we will not make the dashboard ourselves, the paper should not focus on the technical guidelines for creating dashboards.

Table 26 and table 27 show the final searches in Scopus and ScienceDirect. We have filtered the papers based on title, abstract, and complete reading.

Table 29 ScienceDirect included articles Dashboard design guidelines

Source	**ScienceDirect**
Results	87
Title	-82
Abstract	-0
Reading	-2
Forward/Backward referencing	+2
Total	**5**

Table 30 Scopus included articles Dashboard design guidelines

Source	**Scopus**
Results	113
Title	-90
Abstract	-10
Reading	-9
Forward/Backward referencing	+2
Total	**6**

Table 28 shows the articles included in this literature review together with the focus of the paper.

Table 31 Conceptual Matrix Dashboard design guidelines

Author(s)	**Focus**
Few, 2006	Design guidelines for dashboards and common mistakes when designing dashboards

Vilarinho, Lopes & Sousa, 2017	Design procedure to develop dashboards aimed at improving processes
Pauwels et al., 2009	Stages of dashboard development
Yigitbasioglu & Velcu, 2012	Dashboards in performance management with a focus on design and features for end-users
Pastushenko, Hynek & Hruska, 2019	Evaluation of user interface design metrics
Dinmohammed & Wilson, 2021	End-user requirements for data visualization on dashboards
Eckerson, 2005	The design of performance dashboards
Zhou et al., 2022	Systematic review on dashboard design
Sharma et al., 2023	Dashboard design and interactivity
Meignan et al., 2015	The effect of interactivity in dashboards on end-user satisfaction
Bach et al., 2022	Dashboard design patterns

Appendix F 'SLR Implementation plan'

This appendix discusses the systematic literature review we performed to gain knowledge about the implementation of dashboards in companies. The systematic literature review consists of a search strategy, a selection, and an integration of theory. This appendix discusses the search strategy and the selection and Section 6.1 'Literature Implementation Plan' discusses the integration of the theory. In this Appendix, Section ?.1 discusses the search strategy in terms of the knowledge problem, the search terms, academic databases, and a search log. Section ?.2 explains the selection of articles with regard to in- and exclusion criteria and the screening strategy.

F.1 Search Strategy

We have designed the dashboard for Bluetron and now we want to discover relevant implementation methods to write an implementation plan. The problem is that we do not know yet what relevant methods for implementing technical artifacts exist. The question we want to answer with this systematic literature review is the following:

'What are relevant methods to implement the dashboard design at Bluetron?'

The key concepts of the search strategy are 'Method', 'Implement', and 'Dashboard' Table 29 shows the key concepts and their related, narrower, and broader terms.

Table 32 Key concepts Implementation plan

Key concepts		Related terms	Narrower terms	Broader terms
1	**Method**	Procedure	-	Approach
2	**Implementation**	-	Implementation plan, Implementation process	Change
3	**Dashboard**	-	Performance dashboard	Instrument panel, Technology, Artifact

For this literature review, we will use two databases, namely Scopus and ScienceDirect. We use these databases, because they are multidisciplinary and they are offered by the University of Twente.

Table 30 shows the search terms used and the way they were structured for Scopus and ScienceDirect to carry out an accurate and complete search. The first column shows the database we used, the second column shows the search query, the third column shows the number of hits the search produced, and the fourth column shows remarks about the search. The green row is the final search for this systematic literature review.

Table 33 Search log Implementation plan

Database	Search Query	Hits	Remarks
ScienceDirect	"Implementation plan" AND guidelines	6190	Too broad. The next search has to be more concrete.

ScienceDirect	"Implementation process" AND guidelines AND technology	6337	The search is again too broad. I think more emphasis has to lie on technological change
ScienceDirect	"Implementation process" AND "technological change"	929	Going to switch to another database to see whether the search can get a little bit more specific.
Scopus	"implementation process" AND "technological change"	67	Good search. A lot of case studies on implementation processes and even a few review papers on implementation processes. Will use this search.

F.2 Selection

Table 31 shows the in- and exclusion criteria for this systematic literature review. Column 1 shows the inclusion criteria, so the criteria to which a paper has to comply in order to be included in the review. Column 2 shows the justification for the choice of these inclusion criteria. Column 3 shows the exclusion criteria, the criteria for a paper to be excluded from the review, and column 4 shows the justification for these criteria.

Table 34 In- and exclusion criteria Implementation plan

Inclusion criteria	Justification	Exclusion criteria	Justification
Full-text access	Proper citation of papers can only be done once an article is read and understood (van de Weert & Stella, 2019). Therefore, to include the paper in the review, it has to be read to interpret the paper properly.	Non-peer-reviewed journals	Peer review is based on the assumption that it provides a valid measure of quality and adherence to the norms of the field. Non-peer-reviewed journals are more likely to contain errors (Solomon, 2007), and therefore these journals will be excluded from this research
Focus on change management and employee acceptability	The literature suggests that people issues are more challenging than technical issues (Errida & Lotfi, 2021; Mento, Jones and Dirndorfer , 2002; Kotter, 1996; Jick, 1991; Garvin, 2000), we will only focus on papers about change management and employee acceptability.	Focus of the paper lies on the creation of the artifact rather than on the implementation	We want to gain knowledge about implementation plans and therefore want papers that extensively discuss this topic.

Table 32 shows the final search in Scopus. We have filtered the papers based on title, abstract, and complete reading.

Table 35 Scopus included articles Implementation plan

Source	**Scopus**
Total number of hits	67
Selecting based on the title	-60
Selecting based on abstract	-3
Removed after a complete reading	-2
Added (forward/backward referencing)	+3
Total for review	**5**

Table 33 shows the articles included in this literature review together with the focus of the paper.

Table 36 Conceptual Matrix Implementation plan

Author(s)	**Focus**
Garvin, 2000	The General Electric change model
Jick, 1991	The 10-step change model described by the author with a focus on employee acceptability
Mento, Jones and Dirndorfer , 2002	Review paper on the change models by Jick (1991), Kotter (1996) and General Electric (Garvin, 2000).
Errida & Lotfi, 2021	Determinants of organizational change management success.
Kotter, 1996	The 8-step change model described by the author with a focus on employee acceptability

Appendix G Survey Evaluation

This appendix shows the text and statements as shown in the survey to measure the final value of the objectives.

'The purpose of this survey is to measure the effectiveness and efficiency with which employees are expected to gather insights into the bottlenecks of the tape drive test process with the implementation of the dashboard design. We would like to hear what you expect of the situation at Bluetron when this dashboard would be successfully implemented. A difference that is of great importance to this survey is the difference between data and information. With 'data', we mean raw facts and with 'information' we mean structured data that is put in context.

This research is anonymous and we will make sure that the data cannot be traced back to you as employee. Moreover, you are always free to withdraw from the research. If you feel that you have not enough knowledge or information to answer a question, you can skip it.

Thank you in advance for filling in the survey.'

Statement 1.

'Enough data is generated during the tape drive test process to be able to gather insight into the bottlenecks of the process.'

Statement 2.

'The generated data is transferred to clearly interpretable information about the tape drive test process.'

Statement 3.

'The generated data is transferred to clearly interpretable information which gives a complete insight into the bottlenecks of the tape drive test process.'

Statement 4.

'I need the minimal amount of time to acquire clearly interpretable information which gives insight into the bottlenecks of the tape drive test process.'

If you have any questions about one of the statements, please contact us.