THALES

Increasing the predictability of the Radar Front-End Engineering department at Thales NL

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List of Abbreviations

ACT Actual value. 32, 33

AHP Analytical Hierarchy Process. iv, 15, 16, 27, 42, 44, 45

ANP Analytical Network Process. 16, 27, 42, 44

BOM Bill Of Materials. 22, 41, 42

CCPM Critical Chain Project Management. 7, 8

CIDS Configuration Item Design Specification. 22

CITS Configuration Item Test Specification. 23

CTC Cost to come. 32, 33

DevCDR Development Critical Item Design Review. 23

DevOR Development Orientation Review. 22

DevPDR Development Preliminary Design Review. 22

DevRR Development Requirements Review. 22, 41

DevTQR Development Technical Qualification Review. 23

DevTRR Development Test Readiness Review. 23

EAC Estimate At Completion. 32–35, 37, 41, 43

EBOM Engineering Bill Of Materials. 22, 42

FPGA Field-Programmable Gate Array. 1, 22, 23

KAM Key Performance Indicator Assesment Methodology. 42, 45

KPI Key Performance Indicator. iv, v, vii, 2–8, 14–18, 25, 27–29, 31, 32, 36, 37, 41–45, 55–61

OBSO Obsolete. 22

PCA Printed Circuit Assembly. 22

PCB Printed Circuit Board. 22, 23

PDB Programmable Database. 22, 23

PLI Pre-Layout Instruction. 22, 23

PRR Production Readiness Review. 27

RFE Radar Front-end Engineering. iv–vii, 1–8, 15, 20–22, 24–27, 31, 32, 35, 41–45

SI/PI Signal Integrity/Power Integrity. 23

TOC Theory of Constraints. 7, 8

TOPSIS Technique for Order Preference by Similarity to Ideal Solution. 42, 44, 45

TPD Technical Product Documentation. 23

TPDR Technical Product Documentation Review. 23

WPDD Preliminary Work Package Desciption. 22, 41

WPM Work Package Manager. 25, 26, 32, 33, 35, 36, 42

Executive Summary

Introduction
This research is carried out at the Radar Front-end Engineering department of Thales NL. The goal of the RFE department is to increase predictability. However, the current situation makes it difficult to stick to budgets and meet deadlines.

Problem description and motivation
The main research question addressed in this report is "How can the predictability of the RFE department of Thales NL be improved?". This question is explored through multiple sub-questions related to the current state of the predictability, the development process, bottlenecks, Key Performance Indicator (KPI)s, and visualization methods.

Currently, the Radar Front-end Engineering (RFE) department uses a combination of the waterfall-V model, the incremental model, and the iterative model, organized into five phases: orient, design, develop, integrate and verify, and validate. Currently, nine KPIs are used, but these are relatively new which makes them not yet fully reliable. The development process involves six steps: orient, formalize requirements, design, develop, prepare integration and verification and problem integration and verification. Making sure all these phases work together smoothly and resolving issues appeared one of the key challenges.

Main research question
The main research question addressed in the report is "How can the predictability of the Radar Front-end Engineering department of Thales NL be improved?"

Results
Multiple bottlenecks were identified, such as an excessive focus on details, instead of looking at the bigger picture, a lack of communication between different steps in the process, and unrealistic deadlines. These issues contribute to delays and unpredictable projects. This is an important aspect since it shows where the room for improvement is.

To enhance predictability, several methods can be used, such as the Say/Do metric, a system stability analysis, and probability theory combined with a lead time analysis are recommended. Also, well-defined and monitored KPIs are crucial for accurate measurements of predictability. During this research, the say/do metric is used for the predictability calculations, which are shown in the dashboard.

The development of a comprehensive dashboard is proposed as the most suitable monitoring tool, which provides real-time insight and can in the future facilitate a predictive analysis. The developed dashboard is shown in Figure 1 and Figure 2. It includes the current KPIs, capacity for new KPIs, predictability calculations and corresponding graphs, and project milestones. All these features together create a suitable tool for monitoring the predictability of the RFE department.

Recommendations
By streamlining the development process through optimized management techniques and task validation and verification, the predictability of the RFE department can be improved. Implementing clear and measurable KPIs, using predictability calculations, and addressing communication issues and unrealistic deadlines are essential for becoming more predictable, has become clear during interviews with employees.

Further steps include gathering more extensive data to build a historical database, to improve predictability assessments. The Analytical Hierarchy Process (AHP) technique is recommended for an objective KPI selection process. This is not used yet, but some new KPIs are proposed. It is advised that the current KPIs and the new KPIs be evaluated further using the AHP technique to ensure alignment with the goals and objectives.

To improve the flexibility and responsiveness of the current system, adding more components of the agile approach, such as regular meetings (which have already been implemented during the course of this research) in which also the database can be updated, is proposed. This approach focuses on continuous improvement but also ensures that the system is flexible enough to respond to shifting goals and requirements.

Figure 1: Dashboard zoomed in on top part

Figure 2: Dashboard zoomed in on bottom part

Lastly, studying costs incurred from unrealistic deadlines and using this data in negotiations with customers to establish a more realistic deadline is recommended.

Limitations

Several limitations were encountered in this research. Firstly, there were challenges with the available data at the RFE department. Moreover, the available data was not seen as reliable, which became clear during the interviews. Secondly, the scope of the study was on the department itself, potentially limiting insights into broader influences, such as suppliers. Lastly, the findings are derived from the RFE department, which has a specific focus that cannot be easily compared with other departments or companies. This restricts the generalizability of this research to other organizational settings.

Conclusion

In conclusion, this research has explored challenges and opportunities for increasing the predictability within the Radar Front-end Engineering department at Thales NL. The objective of this research is to facilitate more reliable and effective completion of projects, by identifying bottlenecks, suggesting strategic management method changes, and KPI selection. Although there were scope and data limitations, the insights and recommendations provide a base to further improve the predictability of the RFE department.

Preface

Dear reader,

First of all, I want to thank you for reading this thesis. This thesis is the last component of my Bachelor of Industrial Engineering and Management at the University of Twente. My research began with the goal of improving the predictability within the RFE department at Thales NL. It has been an overwhelming, challenging process offering many valuable learning experiences along the way.

Throughout this project, I faced several obstacles, for example with with data availability, and the complexity of both the company and the development process within the RFE department. These challenges tested my problem-solving skills, highlighted the need for careful preparation, and emphasized how crucial flexibility is in a dynamic working environment.

Despite the obstacles, the experience has been very interesting. I learned many things, not only in study-related subjects but also in the working field. This research helped me deepen my knowledge of project management, predictability of projects specifically, and KPIs. These insights are valuable and have significantly contributed to my personal development. One of the biggest lessons I learned is the importance of continuous learning and improvement. I hope that the findings and recommendations presented in this thesis will be helpful for the RFE engineering department, improving their project predictability.

I am grateful to Thales NL for giving me the chance to conduct my bachelor's assignment within their company. Additionally, I want to thank everyone who helped me with this project and hope that this study can be helpful to people who work in the same sector.

Enjoy reading!

Kind regards,

Franka Redeker

July 2024

1 Introduction

In this chapter, the company and the problem are introduced in subsection 1.1. To explore the problem further, a problem cluster is made (subsection 1.2), which shows possible causes of the action problem. Several core problems are shown in this problem cluster, so one core problem is selected in subsection 1.3. After that, the norm and reality is determined in subsection 1.4, as well as a problem solving approach (subsection 1.5). To better understand the research, the research design is shown (subsection 1.6), which shows all research questions. Finally, some deliverables are set (subsection 1.7).

1.1 Company introduction

Thales Nederland is a leading provider of advanced radar technologies and systems for naval ships. The location in Hengelo specializes in naval, environmental competence research, printed circuit boards, and research into human behavior analytics. Within the Radar Front-End Engineering department, front ends for state-of-the-art radar systems, such as antennas, transmitters, signal generators, receivers, and Field-Programmable Gate Array (FPGA) design are developed. Besides these developments, innovative technology studies are carried out. Front ends for state-of-the-art radar systems receive and process signals that the radar picks up. In this way, relevant targets can be detected while minimizing the impact of background noise.

The product developments within the RFE department are performed by highly skilled teams, and according to well-defined engineering processes. By nature, new product developments are less predictable than activities with a more repetitive character. To deliver high value for money and to be more predictable regarding cost and time, the RFE department wants to continuously improve their performance, by using a visualization tool that shows what the current state is, and how to be more predictable.

1.2 Problem cluster

To get a clear overview of the potential problems at the RFE department a problem cluster is made. These are problems that might occur, but not necessarily occur at all times. Further research on the current situation and existing problems is conducted.

In Figure 3 the problem cluster is shown. The action problem "Project requirements based on costs, time or money are not met" is highlighted in green. The action problem is the main consequence of the core problems. The project requirements based on costs are not met. Projects go over budget, which happens because projects take longer than expected. So, the profit is less than expected before the start of the project. Projects take longer than expected because new iterations are needed, because of technical issues that come up during the development process, a lack of engineering skills, and because materials have a long lead time, or are not delivered in time. The technical issues can happen because tests are performed too late, or due to the technical agreements or assumptions made before the development process started being wrong. Tests can be performed too late because previous tasks have been delayed. Technical assumptions can be wrong as some tasks are performed by inexperienced employees, who usually take longer to do the same task than employees who have worked there for over 30 years. Some people are inexperienced because there are not enough people to educate all employees, and therefore this process also takes longer. The balance between experienced and inexperienced workers is therefore not always right. This leads back to a 'lack of engineering skills', which is also caused by the fact that there are not enough people available to educate new employees.

Now we look at the long lead times of materials, and materials not being delivered on time. This happens because sometimes an order cannot be placed if the task before that is not ready, as it is not always possible to predict how many and what type of materials/products are needed. Also, the companies to which some processes are outsourced are less flexible if the project does not go according to the pre-made planning. They base their schedule on project plans of multiple companies (customers), so they do not always have time at the same time which is useful for Thales, in case of delays. Sometimes, outsourcing promises that they are capable of doing something, but during the process, they find out that they are not capable. This can be because for example they do not have the equipment anymore, or a skilled employee left the company for example. Although these two causes end on a chain, they are not core problems since the problem owner is the outsourcing company, not the RFE department. Both 'orders can't be placed yet' and 'outsourcing companies are less flexible because of other projects from other companies' are caused by an accumulation of tasks, which are caused by delays of previous tasks. These delays of previous tasks are caused by inaccurate planning of the development process, which is caused by a lack of customer info, a poor insight into the performance of the RFE department, and a lack of predictability, which are all core problems. It can also be caused by the lack of information flow from one activity (A) to the next activity (B). Sometimes engineers only start thinking about what needs to happen and which information is needed to start the next activity, which causes delays. This is caused by a lack of alignment between teams and sub-teams, which is also a core problem.

Less profit is also caused by customers who leave for competitors for future projects. They leave because they are dissatisfied, as the delivery deadline is not met. The delivery deadline is not met as the set deadline is not always realistic, there can also be unforeseen circumstances that cause an unrealistic deadline. Sometimes the management from higher up just does not want to spend too much time looking at their Excel sheets. Due to the Excel sheets, they also assign too little budget to tasks. Because the project managers must meet the goals of the people from higher up, they assign too little budget and time to tasks, which is also a core problem.

1.3 Core problem selection

The lack of predictability is chosen as the core problem. Lack of predictability results in an inaccurate planning of future projects, but it is also caused by inaccurate planning and a lack of trustful data. Poor insight into the current processes could also be a suitable core problem, but solving this problem would not add much value to the project since multiple people are already looking into it at the company. There are already multiple visualizations about KPIs available. A lack of customer info is hard to solve, other than making sure you have enough info by using a checklist for example. A lack of alignment between teams is also difficult to solve because teams have different perspectives and goals, who is going to decide which goal or perspective is the most important? Moreover, the project must be done in the RFE department, and if the focus is on aligning teams, it would cover multiple departments, which is too complicated for the little time available. Too little budget assigned to tasks is a problem caused by people of the headquarters in France, which we also cannot solve. Therefore, the lack of predictability of development processes is the best problem to focus on during this project. Moreover, focusing on the problem of predictability will add the most value to the company, since it will make the department run more efficiently. If the department becomes more predictable, in the end, the project will finish on time, which leads to more profit.

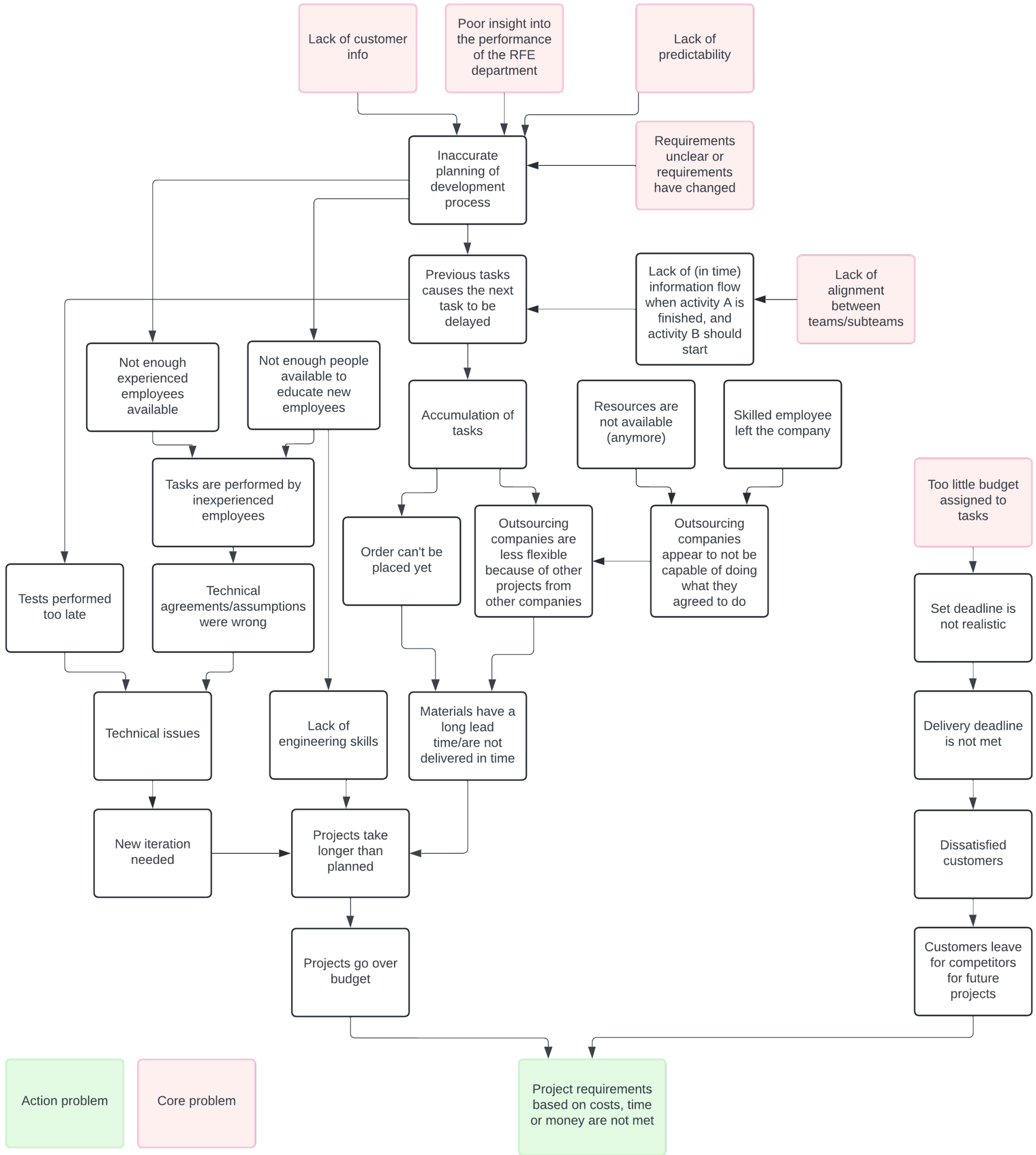


Figure 3: Problem cluster

1.4 Description of norm and reality

The norm of the RFE department is to have a clear overview of what is going wrong in which processes. It must be a visual representation showing the current performance and where they can improve. Furthermore, they should keep track of the process, regarding predictability. A consequence of this norm would be that the department achieves its goals and milestones, and it can fix the issues and make more profit.

The reality is that a clear overview of processes is missing. This makes the department hard to manage because it takes a lot of time to find out what part of the process takes too long, and what the reason is for this. Projects often take longer than expected, and because more hours have been worked, the costs also go up, and therefore the RFE department often goes over budget.

Predictability itself is complicated to measure, but we can look into some KPIs, and compare the planned number to the actual number. Planning accuracy of ongoing projects (initial date and actual date), is 57 days, measured in March 2024. The goal is 0 days, but within 5 days is acceptable. However, this data seems unreliable because of high deviations and negative numbers.

1.5 Problem solving approach

To find out how the RFE department can gain more insight into their current performance and make the development process more predictable, it is useful to use research methodology. One of the deliverables is a visualization of the current state of the department, so the DRSM (Peffers et al., 2007) is used. This is a systematic approach to researching information systems. Four research entry

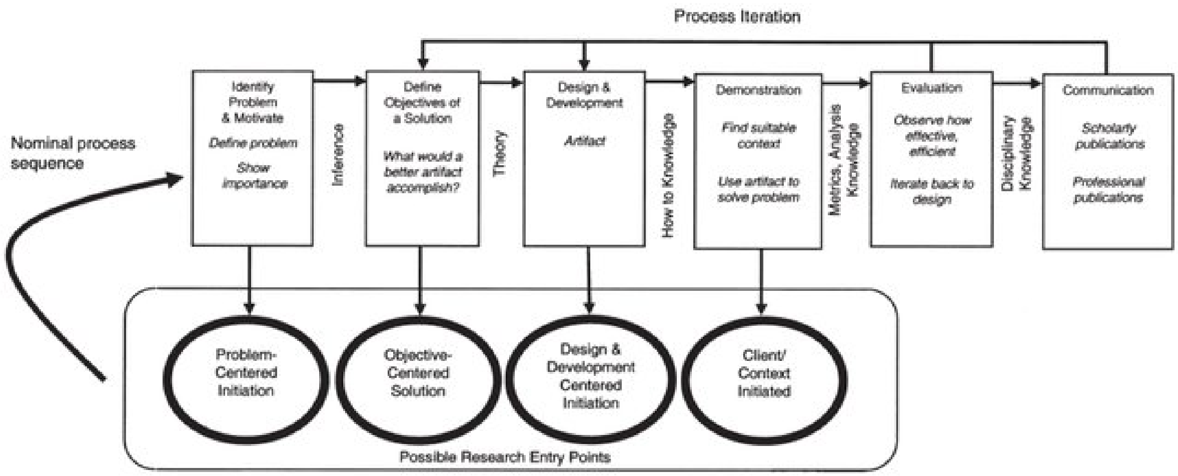


Figure 4: DSRM model. From *A Design Science Research Methodology for Information Systems Research*, by K. Peffers, T. Tuunanen, M. A. Rothenberger, & S. Chatterjee, 2007, *Journal of Management Information Systems, 24*(3), 45–77. Copyright 2007 by Ken Peffers. (http://dx.doi.org/10.2753/mis0742-1222240302).

points are described with the KPI (Figure 4): a problem-centered initiation, an objective-centered initiation, a design- and development-centered initiation, and a client/context-centered initiation. In the first step, 'identify problem and motivate', the problem is identified and motivated. This will be done by looking through the existing databases and talking to employees. For the second step, 'define objectives of a solution', the same thing will be done.

In order to proceed to the third level, "design and development", certain tasks need to be completed. We will begin by identifying the current situation and investigating the existing processes and their bottlenecks. When this is done, we can start looking into suitable KPIs. Lastly, we will investigate how to visualize these KPIs. When all this information is gathered, the development of a visualization tool can be started.

When the visualization is finished, a demonstration will be presented, as step 4 indicates. For step 5, 'evaluation', an evaluation of the model is done. It is checked if the visualization shows what it has to show by doing a User Experience Questionnaire among the target group. See Appendix I for the survey questions. To complete step 6, a thesis report will be written, which shows all steps of the process and their outcomes.

1.6 Research design

In the research design, the main research question and its sub-questions will be introduced. The sub-questions are based on the KPI model. The type of research, key variables, source of data, outcomes, and limitations are discussed for each sub-question. In the end, the validity and reliability of the research is discussed.

1.6.1 Knowledge problems

The main knowledge problem that needs to be solved is a lack of insight into current development processes, and therefore the lack of predictability of these processes. Therefore, the following main research question can be formulated: "How can the predictability of the RFE department of Thales NL be improved?"

1.6.2 Sub questions

The first step of the KPI is the identification and motivation of the problem. This is already executed in the section 'Problem identification' and 'motivation of the core problem' parts of the introduction, and hence it does not have to be a separate research question. The second step is defining the solution's objectives, which is done in section 1 of the project plan.

The third step is the design and development phase. To complete this step, five research questions are answered. Before starting with improving a process, it is important to look at the current situation. We must know what the current situation regarding quality, cost, and time is. Therefore, the following research question and sub-questions can be formulated:

1. "What does the current situation of the Radar Front-End engineering department look like, focused on quality, time and costs?"

- **a.** "What models exist to manage quality, time and costs?"
- **b.** "Which KPIs are currently used?"
  - **i.** "How relevant are these KPIs in terms of predictability?"
  - **ii.** "How can these existing KPIs be used?"
- **c.** "How reliable are the current predictions?"

Another aspect of the design and development phase is looking into the development process. Also looking into the bottlenecks, and possible patterns of bottlenecks of the development process is important, therefore the following questions are formulated:

2. "What does the development process on the Radar Front-End Engineering department look like?"

3. "What are the bottlenecks in the development process of products in the RFE department?"

- **a.** "How can bottlenecks in the development process be detected?"

The KPIs shown in the dashboard must be relevant for the department. The milestones must be shown, but it does not make sense to show data of a project that finished a long time ago, since it is not an active project. As a result, a subsequent question has been created.

4. "How can predictability be measured in the RFE department?"

- **a.** "How can predictability be measured in general?"
- **b.** "What are the selection criteria for KPIs?"
- **c.** "What is the best method to select KPIs?"
- **d.** "What are the goals of the company, and how is this measurable?"
- **e.** "Which KPIs are relevant for the department to monitor the performance and predictability?"

Part of the development and design process is finding out how to visualize the KPIs. The KPIs must be shown in a clear overview so that the user can understand the current state of the department easily. The following question helps to get more knowledge about how a dashboard looks like, and what layout is suitable. This research question will be answered with a systematic literature review.

5. "What is an effective way to visualize the KPIs to give more insight into the performance and predictability?"

The fourth step of the KPI is the demonstration of the model. To complete this step, a visualization is made, showing the KPIs of the RFE department. The results are shown in research question 6. Also, an evaluation of the model is done in question 6.

6. "How can the visualization help to become more predictable?"

The final step of the KPI model is 'communication'. It is not necessary to formulate a research question to complete this step since all findings are shown in this thesis, which will be presented to the company.

Table 1: Research design

Research questions	Type of research	Key variables	Source of data	Outcomes	Limitations
1. What does the current situation of the Radar Front-End engineering department look like, focused on quality, time, and costs?	Descriptive, qualitative, and quantitative	Lead times: the time it takes to complete a task or process, Costs: all costs made during a task or process, Key performance indicators: quantifiable metrics with which the performance of a process can be measured	Existing databases and process flows	Charts and graphs with information about the current performance	Lack of available data
2. What does the development process on the Radar Front-End Engineering department look like?	Descriptive, qualitative	Development process: stages involved in developing a new product	Existing databases, semi-structured interviews with employees	Process mapping	Processes are not correct, not available or executed according to plan, employees give contradicting answers
3. What are the bottlenecks in the development process of products in the RFE department?	Exploratory, qualitative	Bottlenecks: constraints and inefficiencies in the process that cause delays	Existing databases and semi-structured interviews with employees	Process flow analysis, root cause analysis	Lack of data available, bottlenecks are not concrete, employees give contradicting answers
4. How can predictability be measured in the RFE department?	Exploratory, quantitative	Key performance indicators: quantifiable metrics with which the performance of a process can be measured	Existing databases and semi-structured interviews with employees	KPI identification and overview	Stakeholder bias
5. What is an effective way to visualize the KPIs to give more insight into the performance and predictability?	Applied, quantitative	Key performance indicators: quantifiable metrics with which the performance of a process can be measured	Systematic literature review	A visualization method	Assumptions must be made; visualization must be easy to interpret
6. How can the model help to become more predictable?	Applied, quantitative	Model: a visual tool that shows historical data and patterns that indicate possible lateness and higher costs	Visualization model made in question 5	Model analysis	Assumptions are needed to make a model

1.7 Deliverables

A broad overview of the deliverables can be found in the research design table (Table 1). A visualization of the performance of the New Product Innovation processes on the Radar Front-End department will be provided. Moreover, an analysis report of this visualization will be provided to help the reader understand what the data means. All this together will help the RFE department to be more predictable.

Sub-deliverables are a process map of the development processes, a process analysis/root cause analysis, and KPI identification.

2 Literature review

In this chapter, literature reviews are done on various subjects. First, the theoretical framework is discussed in subsection 2.1. This section mentions several theories that are used throughout the research. The theoretical framework answers research question 3a, and it shows the theory behind research question 5. In subsection 2.2, characteristics of project management are described, such as the iron triangle, quality, cost, and time, answering research question 1a. subsection 2.3 shows the differences between hardware and software in subsubsection 2.3.1, and it describes several resource-saving methods (subsubsection 2.3.2), and time-saving methods (subsubsection 2.3.3), which also contribute to answering research question 1a. subsection 2.4 gives the definition of predictability and describes different measurement methods of predictability, answering 4a.

In subsection 2.5, research is done to determine KPI selection criteria, answering research question 4b.subsubsection 2.5.1 describes multiple ways to select KPIs, which can be used that evaluate the KPIs in further research. This also answers research question 4c. To define new KPIs that are more focused on predictability, literature research in this field is done in subsubsection 2.5.2, contributing to the answer to research question 4e. In subsection 2.6 a systematic literature review is done (details can be found in Appendix G), to determine the best visualization method. This provides the theory behind the answer to research question 5. In subsection 2.7 the visualization approach for the dashboard is described, including research regarding dashboard requirements and design stages which answers research question 6.

2.1 Theoretical framework

Here, the theoretical perspective of the research is explained. Sub question 5, "What is an effective way to visualize the KPIs to give more insight into the performance and predictability?", is answered by doing a systematic literature review, and the main findings of this review are summarized in 3.1. Moreover, the Capability Maturity Model Integration is introduced.

2.1.1 Theoretical perspective

Theory of constraints
The Theory of Constraints (TOC) is focused on the weakest links in the chains (Şimşit et al., 2014). It sees processes as links of a chain, instead of independent processes. TOC is based on the idea that every system has at least one bottleneck which can be improved, to reach a higher performance level. Managing these bottlenecks results in a continuous improvement of the management system. The constraints in this research will be referred to as bottlenecks.

The TOC is relevant because it helps determine the bottlenecks that interfere with the performance and predictability. Moreover, the TOC focuses on where the most improvements can be made, so it is of most value to the department.

Root cause analyses
Root cause analysis is a problem-solving method that supports companies in their continuous improvement process (Ito et al., 2022). Root causes are the underlying causes of an issue or bottleneck. To find the root cause of a problem, multiple techniques can be used, such as the five whys, fish-bone diagrams, cause and effect analysis, fault tree analysis, and Six Sigma. According to a literature study (Ito et al., 2022), there are three main problems: an alarm flood (large volume of alarms happening simultaneously), the need for expertise to identify the issue, and employee bias.

Root cause analysis is of value because it aims to understand the reason why the RFE department is not as predictable as it would like to be. Moreover, it relies on data, so well-informed decisions can be made.

Critical chain
Critical chain is an extension of the theory of constraints, specifically focused on project environments (Raz et al., 2004). It is an alternative method for planning and control, compared to the classical methods. Critical Chain Project Management (CCPM) starts with a list of tasks, together with their duration estimates and dependencies. Then, an initial schedule for project tasks is developed. This schedule is likely to be longer than a basic critical path method schedule because some of the resources

are limited. The critical chain is the set of tasks in the longest path to project completion, after resource leveling. In CCPM, the concepts of bottlenecks and material buffers are developed within the TOC.

Critical chain is used because it manages uncertainties and variations in project timelines. Moreover, it addresses the topic of buffer management, which decreases the impact of issues on the final delivery date.

Visualization method

Based on the systematic literature review (chapter 7.1), a decision of strategy for visualizing KPIs can be made. Since KPIs can be used for monitoring the success or failure of an objective during a process, first KPIs need to be selected. This will be done in research question 5: "What is an effective way to visualize the KPIs to give more insight into the performance and predictability?".

After the KPIs are selected, a visualization of these KPIs must be developed to easily monitor them. The goal is to see within one view what the current state of the processes is. Before developing a visualization, a visualization method needs to be chosen. In the systematic literature review, multiple methods are mentioned, namely a dashboard, a balanced scorecard, benchmarking, and a SWOT analysis.

An operational dashboard is the most suitable option since it is used for analyzing, selecting, and displaying KPIs, focused on operational processes. It monitors real-time performance, so it is easy to conclude this visual overview. It is also possible to do a predictive analysis and determine trends and patterns from a dashboard, which helps the company to get more predictable. A balanced scorecard evaluates the company's performance, but it is more focused on implementing a strategy, compared to a dashboard. Since the core problem does not have anything to do with implementing strategies, this option is not suitable.

Benchmarking is a continuous systematic process of measuring the outputs of processes, and its focus is on protecting the company from the competition. The core problem is not just focused on measuring outputs, but also on what the outputs mean and what the consequence of an output is, so benchmarking does not cover the full goal of solving the core problem. Moreover, the core problem does not have anything to do with competition.

A SWOT analysis is focused on defining the strengths, weaknesses, opportunities, and threats. It is essential for strategic management, which is not relevant in this case. Although a SWOT analysis is not a suitable visualization method, finding strengths, weaknesses, and opportunities could help to define the current situation. So, a full SWOT analysis is not useful, but certain parts could be used to answer research question 1: "What does the current situation of the Radar Front-End engineering department look like, focused on lead times and costs?". So, to visualize KPIs and get more information on the performance of development processes, a dashboard will be developed.

Capability Maturity Model Integration

While researching question 1: "What does the current situation of the Radar Front-End Engineering department look like, focused on quality, time and costs?". It is also good to investigate the level of maturity of Thales, and the RFE department specific. This will be done by using the Capability Maturity Model Integration (CMMI, Figure 5). The CMMI model is an improvement model, that can help to find performance issues in an organization (Yamfashije, 2017). It can help us to understand and solve problems, eventually improving the company's overall performance. Overall, it can help to improve productivity, improve quality and reduce defects for example.

The CMMI defines five maturity levels, each level represents a group of process areas. Level 1 is 'initial', which are chaotic, unordered, and undocumented processes. Level 2 is 'managed', these processes are repeatable, and they might lead to consistent results. These processes are well-documented, and often these processes are maintained during times of stress. Level 3 is 'defined', these are standard, well-defined, and documented processes. Level 4 'quantitatively managed' focuses on quantitative management and uses data analysis to make decisions to improve process performance. Level 5 'optimizing' is the highest level of maturity. This focuses on continuous improvement, based on the quantitative understanding of the business objectives and needs of the performance.

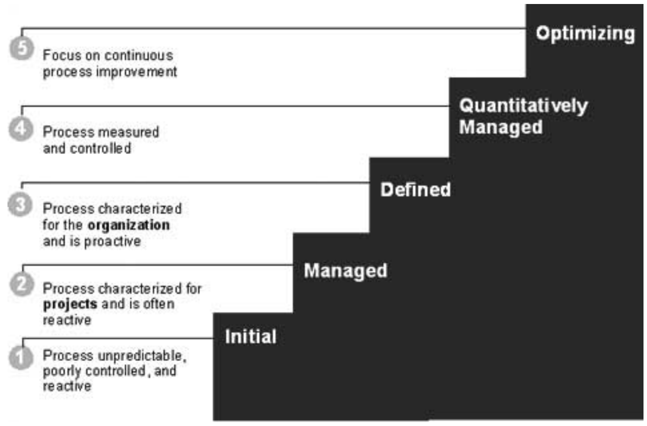


Figure 5: CMMI model. From *CMMI Maturity Levels*, by TutorialsPoint, 2023, TutorialsPoint (`https://www.tutorialspoint.com/cmmi/cmmi-maturity-levels.htm`).

2.2 Project management characteristics

Project management is "the application of processes, methods, skills, knowledge, and experience to achieve specific project objectives according to the project acceptance criteria within agreed parameters" (AssociationForProjectManagement, 2024). The building blocks of a project are time, costs, and quality. So, a project is successful if it meets the quality criteria, within an agreed time and budget. These three characteristics are difficult to manage since they are closely related. A change in one of them will influence the other two, thus the project's outcome. Figure 6, shows the quality-cost-time relationship model. This figure shows what happens with the time and costs, in a certain quality situation. For example, if rework or repair is needed, time and costs will be added.

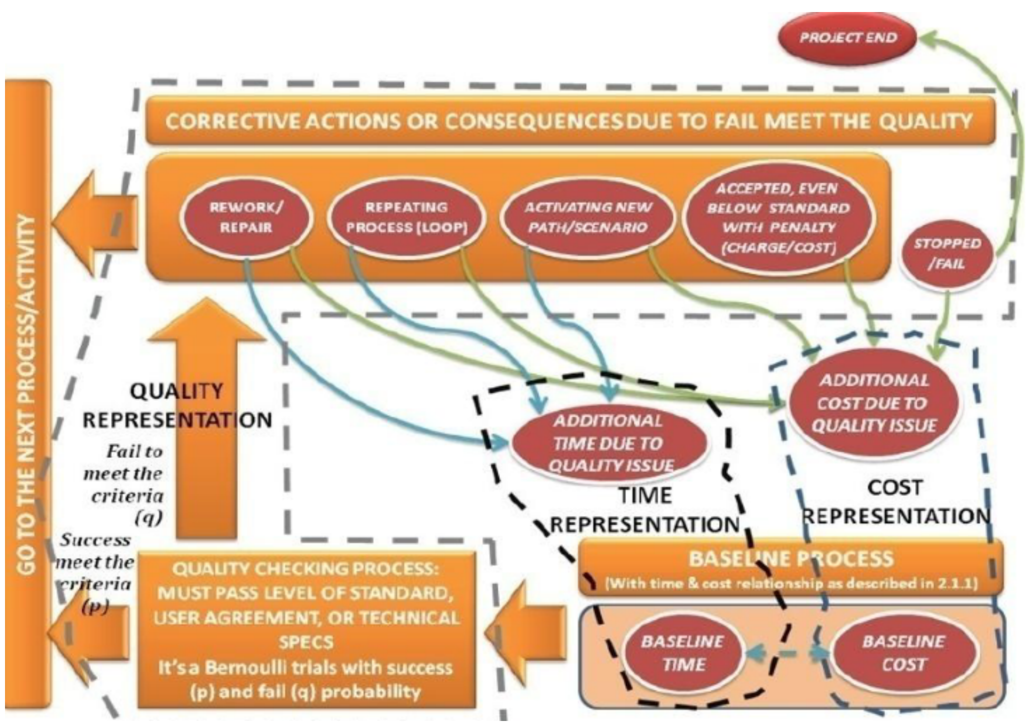


Figure 6: Quality-cost-time model. From *Project management: cost, time and quality*, by B. Stojcetovic, D. Lazarevic, D. Stajcic, & S. Miletic, 2013, *Proceedings of the Faculty of Economics in East Sarajevo*. Copyright 2013 by B. Stojcetovic.

Iron triangle
The 'Iron Triangle' places quality, costs and time in a triangle. The center of the concept is the mutual dependency between the three constraints (Stojcetovic et al., 2013). If the quality increases, the amount of time will be increased. However, a time limit can decrease quality and increase costs, since the same work must be done in a smaller time. Before implementing the triangle, it must be clear which constraint is the most important and least important for a specific project. The impact of certain actions needs to be evaluated, and therefore a range of options can be given. For a project to be successful, a good balance needs to be found. Sometimes scope is used instead of quality. Researchers (Bourne and Walker, 2004) say that one of the main elements of the scope constraint is quality.

Quality
Quality is defined as "the degree to which a set of inherent characteristics fulfill requirements", according to the Project Management Institute. Inherent characteristics can be a product, process, or system. Before the project can be planned, the quality requirements need to be clear. If the quality requirements are met or exceeded, the project has been successful. Delivering a project on time, and within budget, but not meeting the quality requirements will not be successful, because a project must be profitable. If the project does not meet the quality requirements, the project will not be sold, and therefore it is not profitable. If the project needs rework or modifications, the time and costs will go up and the project may fail. To avoid this rework, it is important to do regular quality checks.

Many quality issues are specific to projects (Stojcetovic et al., 2013). First, project quality is a difficult characteristic to measure. Stakeholders cannot evaluate the quality until the realization of the project, and at that stage, it is too late to resolve gaps, or it will lead to high costs and delays. Second, there are no, or very few standard quality evaluations that can be used because project outcomes are new and unique. Planning the quality of work is more cost-effective than doing rework and correcting issues. Quality also has some benefits in projects. A project or product of quality leads to customer satisfaction. It also reduces waste, which directly leads to a cost reduction, and therefore profits go up. Because tasks do not have to be redone, productivity increases. And as the products get better, the project performance gets better, and the competitiveness increases.

Costs
Managing a project's costs includes estimating the costs, budgeting, and controlling costs to ensure it does not go over budget. So, the monetary resources to complete activities in a project need to be estimated, creating a cost baseline by adding up all expenses, and monitoring the status of the project. Cost of quality has 3 sources: failure, prevention, and appraisal. Internal failure includes costs of rework and costs associated with disposal, storage, transportation, and inventory control. External failure occurs after the delivery of a product, think of repairs within warranty, and product recalls. A result of external failure can be the loss of customers. Prevention costs are the costs that appear before the product reaches the customer. Good planning prevents high costs later in the project, as well as the requirement of changes later in the project. Appraisal costs start with the inspection of incoming supplies. If the quality of the materials used in a project is not good, the whole project is affected by this.

Time
The goal of time management is to complete a project within the agreed time. It mainly consists of planning, control, and execution. A lack of planning usually leads to high costs. To know how much time is needed, first, the required time for implementation of each activity needs to be determined. Therefore, the project needs to be broken down into smaller activities in a logical order, and it needs to be determined what resources each activity needs. In case the project needs to be finished in a short time, resources need to be increased and therefore the costs increase. If a deadline must be met, it can also result in a cut in quality.

2.3 Management models

2.3.1 Hardware vs. software

Most management models are suitable for software, but that does not mean they are also suitable for hardware. Hardware is harder to change, and the costs of change are much higher. Also, software evolves through multiple releases by accretion and refactoring (Thompson, 2024). Hardware consists of large physical components, which cannot be refactored after manufacturing.

However, for both, the development cycle can be divided into many small and testable deliverables (Thompson, 2024). For hardware, the deliverables do not produce a steady flow of usable features until later in the process, but the deliverables can still be tested throughout the cycle. Agile can also be used for hardware, but the sprints can be more of a feedback moment, instead of having a clear deliverable. The sprint also usually takes twice as long for hardware development (Salimi, nd).

2.3.2 Resource saving methods

Projects with a strict budget, but a flexible timeline will profit from a resource-saving method. If resources are limited, costs will be saved, but the project will take longer. Therefore, we investigate several resource-saving methods in this subchapter.

Waterfall method

With the waterfall method, project phases are completed sequentially. This requires a flexible timeline because if an activity is delayed, all subsequent phases need to be adjusted. The waterfall method exists in six stages (see Figure 7). The waterfall model is simple and easy to understand and has clearly defined stages (Khan, 2023). This makes it easier to arrange tasks. The waterfall model works well with small projects, and it is an easy-to-manage model because of its rigidity.

The downsides of the waterfall model are its high number of risks and uncertainty (Khan, 2023). It is not the best model for long and ongoing projects, and projects for life-critical systems. It is difficult to manage the progress of projects within the stages, and it is hard to combine the waterfall model with an object-oriented approach. Lastly, the waterfall model does not deal well with changes in requirements during the process.

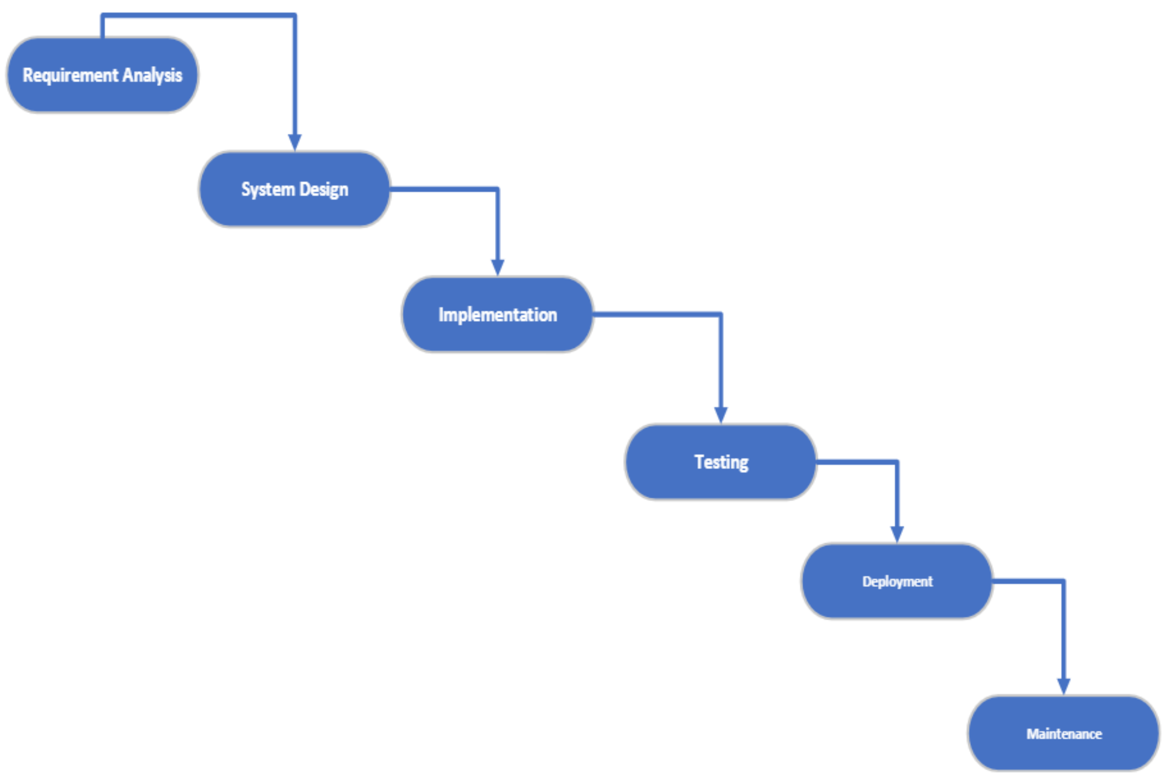


Figure 7: Waterfall model. From *Waterfall Model Used in Software Development Reference: Software Requirements Engineering Waterfall Model*, by S. M. A. Khan, 2023, *Unpublished*.

V-model

The V-model is a development of the waterfall model. The difference is that the V-model identifies defects during the testing phase, while the original waterfall model identifies defects at the start (GeeksForGeeks, 2024). The V-model is also known as the verification and validation model. It is a sequential process in which the next phase can only begin if the present phase is finished. The model consists of project definition (orient and design), implementation (develop) and project test and validation (integrate and verify, and validate). During the project definition, the requirements are mapped, and when they are clear, the work of technical design is done. During the implementation phase, the design is worked out. During the test and validation phase, each step on the right is testing a phase on the left, e.g. modules are specified on the left, and tested on the right. A risk of the V-model is the lack of SMART definition on the left (Marselis, 2020). It is difficult to validate if it is not clear how something should be measured, and sometimes it is not possible to measure something at all. A pro of the V-model, compared to the waterfall model, is that it is easier to understand and apply, it is a very disciplined model, and it needs to be completed before moving to the next phase. Moreover, it includes a review after each phase, which works as a control, or check moment to make sure it is right (Auvee, 2024).

Lean management method

The lean management method is aimed at improving quality and efficiency by identifying and eliminating waste within processes (Jovanovic et al., 2023). Lean management intends to maximize value while minimizing resources, time, and effort. A key component of lean management is understanding customer value, therefore, a customer-centric strategy is needed to improve overall stakeholder satisfaction. Another component of lean management is eliminating waste, to streamline processes and improve operational effectiveness. This dedication to eliminate waste often comes together with a culture of continuous improvement, known as Kaizen. This encourages employees to provide suggestions for streamlining processes and reducing inefficiencies. This makes the empowerment of employees also a vital component of lean management.

2.3.3 Time saving methods

Time-saving methods are useful for projects where the focus is on a strict deadline. Downtime can be eliminated, so teams can continue working.

Agile

The agile method is a management approach, mainly used in software development. It prioritizes incremental and iterative development (Sharma et al., 2012). A key characteristic is its flexibility to adapt to changes in requirements, which allows for quick responses and feedback. The focus with agile is on customer involvement throughout the development cycle, which ensures that the final product aligns better with user expectations. There is also a big focus on teamwork in the agile method, by collaborations among team members for example.

Another aspect of the agile method is little documentation, which speeds up the development process (Sharma et al., 2012). Only the critical paperwork that immediately supports the project is done, such as feature lists and iteration timelines, leaving more time for actual developments. Using the agile method, each iteration is seen as an opportunity to refine both the product and the development process. Overall, the agile method intends to improve productivity, performance and risk management.

Scrum

Scrum is a specific form of agile management. It is often used in software development, and it utilizes sprints and daily touch bases with the team, to minimize time losses in work-in-progress phases (Scrum.org, nd). The three pillars of scrum are transparency, inspection, and adaptation. A scrum team has a scrum master, product owner, and developers who are responsible for transforming the work selection process into a sprint to increment value (see Figure 8). Advantages are the quick and efficient deliverables and the effective use of time and money. On the other hand, scrum often leads to scope creep, because there is no definite end date. It also requires a lot of commitment and cooperation from a team.

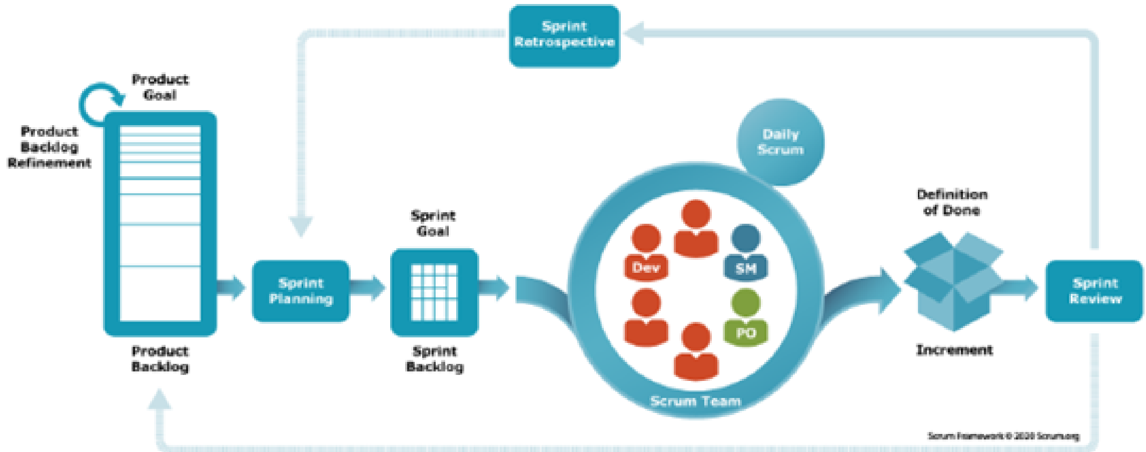


Figure 8: Scrum model. From *What is Scrum?*, by Scrum.org. Retrieved from `https://www.scrum.org/resources/what-scrum-module`.

Kanban

Kanban minimizes the time wasted on work-in-progress by using a continuous, clearly visible shared process. The visualization can be done on a digital or a physical board, and it standardizes the workflow and identifies and resolves all obstacles and dependencies right away. Benefits of the Kanban method are planning flexibility, shortened time cycles, fewer bottlenecks, visual metrics, and continuous delivery (Radigan, 2024). The downside of the process is the oversimplification of tasks, the information overload, difficulty in tracking long-term progress, and challenges in team collaboration (dos Santos et al., 2018).

Scrumban

Scrumban reduces the amount of time spent on work-in-progress by combining the daily team activities of scrum management and using the collaborative and continuous nature of the Kanban method. The Scrumban method works well for splitting up large projects into smaller pieces, it enforces transparency, and it identifies and reduces bottlenecks (Incubator, 2020). On the other hand, it offers the team manager less control, has little documentation and it can be hard to track and monitor.

Incremental model

An intuitive way to approach the waterfall model is through the incremental model (Brown, 2020). The incremental model uses several iteration of smaller cycles, including requirements, design, development, testing and user feedback (section 2.3.3). Each iteration improves the previous iteration. It is also an effective method for improving the viability of a strategy. This is useful in case of innovative systems where it is unknown if constraints can be met, or where methods may be developed to carry out the requirements.

The iterations create smaller cycles, which makes testing and management easier and allows for early error detection (Brown, 2020). This is useful when requirements change throughout the process. A drawback on the incremental model is scope creep, which can result from frequent user feedback, creating a risk of becoming trapped in an endless development cycle. When the requirements for the complete system are not obtained at the start of the project, it has to be revised later, which may impact the system design in later iterations,

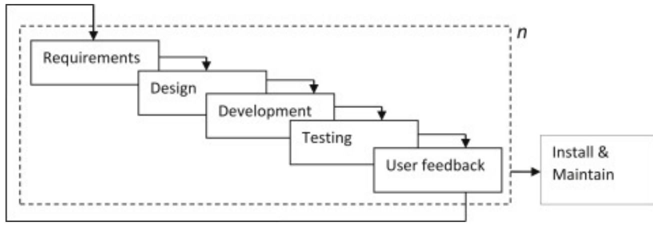


Figure 9: Incremental model. From *Software Engineering*, by A. S. Brown, 2020, *Clinical Engineering*, chapter 9.

2.4 Predictability

Product development is focused on the flow of information, in contrast to other processes, where the focus is on material flow. Moreover, development processes are mainly cognitive, instead of physical.

2.4.1 Definition

The extent to which future results can be predicted using available knowledge or data is referred to as predictability. It is essential for risk management, policy formation, and decision making (Diebold and Kilian, 2001). Predictability can fluctuate significantly, depending on the factors, time spans and models used. If the organization is predictable, it can rely on its metrics and data to make a realistic prediction on delivery dates (Bancroft-Connors, 2022).

2.4.2 Measurements

Say/do metric
The say/do metric is the ratio of planned work to delivered work in a time box, so it compares what someone says they will do and what they achieve (Scotland, 2021)This only works when time-box planning is used, so it does not work for a flow, or pull-based process. Moreover, both numbers used to calculate the ratio are estimated, which makes it less accurate, so it is also prone to bias. On the other hand, it is a seemingly clear measure of progress and accountability (Hinshelwood, 2024).

System stability
To say if the system is predictable, it is interesting to investigate system stability. An unstable system, with special cause variation, is unpredictable (Scotland, 2021). If the special cause variation is removed, a common-cause variation is left, which makes the system predictable. So, to have a stable system, the noise of special cause variation needs to be removed.

To measure stability, an easy calculation (Healy et al., 2023) can be done, the service rate is divided by the arrival rate. The arrival rate is the number of tasks added to the list, and the service rate is the number of tasks successfully done in the same period. If the ratio is less than one, the system is unstable. When it is equal to one it is optimally stable, and when greater than one it is stable. To improve predictability, one can investigate historic patterns to determine system stability.

Meeting expectations
You can also think of predictability as meeting expectations. This can be accessed by using probability theory. If the outliers in the data are removed, a system is more predictable (Scotland, 2021). Looking at lead times, the lower the lead time coefficient of variation is, the more predictable the system is. Also, a narrow lead time distribution is more consistent with each other and leads to more reliable predictions.

2.5 Key Performance Indicator selection criteria

KPIs can be categorized into four categories: strategic, operational, functional and leading/lagging (Twin, 2024). Strategic KPIs indicate how a company is doing, on a high level. Operational KPIs measure how a company is doing in a shorter period. They analyze processes, segments, or geographic locations. Functional KPIs dive deeper into specific departments or functions within a company.

Leading or lagging KPIs clarify the type of data that is studied, and whether it relates to an upcoming or previously occurred event. The KPIs chosen for the RFE department will be focused on process performance.

A well-defined KPI uses the SMART criteria (Tableau, 2024). SMART stands for specific, measurable, achievable, realistic, and time-bound. Using SMART criteria results in concrete metrics and milestones. For a KPI to be specific, it must be clear what the goals and expectations are. It is important to have measurable KPIs, otherwise it does not indicate if you are performing well. It is also important to be within realistic capabilities and set achievable goals. The goal should be within reach, as well as it should be relevant. The final criterion is time-bound. This can be a start or endpoint for example, there might be a deadline before which a certain objective should be met.

According to Mu and Pereyra-Rojas (2017), seven characteristics of KPIs can be defined. The measures should not be financial, measured frequently, and acted on by the senior management team/CEO. Moreover, they should clearly indicate what actions are required by staff, and they need responsibility to a team. Finally, KPIs should have a significant impact, and they should encourage appropriate action.

2.5.1 Key Performance Indicator selection methods

While selecting KPIs, different methods can be used. Multi-criteria decision analysis is focused on finding a compromise solution. Preference information is provided by the decision maker, and they also incorporate subjective information (Hester et al., 2017).

Key Performance Indicator Assessment Methodology (KAM)
KAM can deal with emergent manufacturing processes and can help to assess the KPIs to realize the corporate goals (Hester et al., 2017). Figure 10 shows the KAM, the methodology is divided into two phases, the KPI characterization and the KPI alignment and balance. To summarize the figure, first, an orientation is done, then KPIs are decided, and criteria are weighted. Then each KPIs gets a score, based on the criteria, and finally, KPI pair issues are identified, and results are discussed.

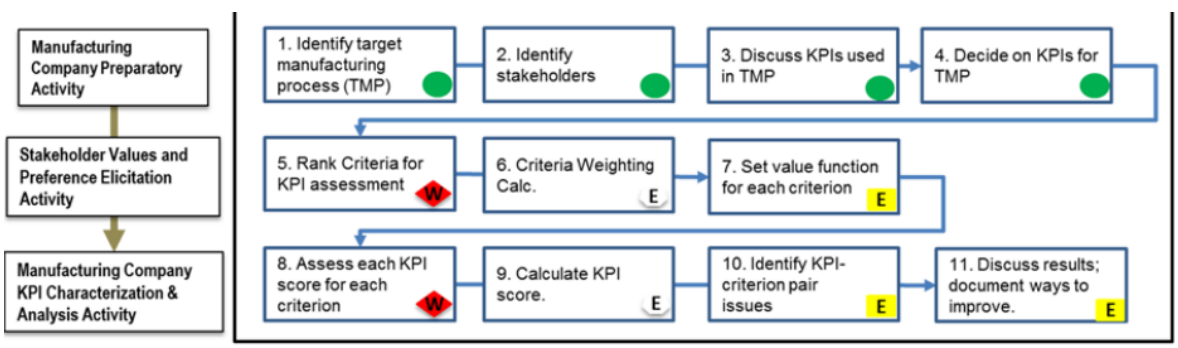


Figure 10: KAM method. From *A Method for Key Performance Indicator Assessment in Manufacturing Organizations*, by P. Hester, B. Ezell, A. Collins, J. Horst, & K. Lawsure, 2017, *International Journal of Operations Research, 14*(11), 157-167.

Analytical Hierarchy Process (AHP)
The AHP is focused on solving complex decision-making problems in a relatively simple manner (Podgórski, 2015). It is a multi-criteria decision analysis, that can solve problems with more than one decision criterion. The AHP is implemented in four stages. It starts with breaking down the decision problem and creating a hierarchical model of the criteria and decision options that affect the solution. Then criteria are compared pairwise, and a vector of weights needs to be created for each criterion. Then, the decision options need to be compared pairwise, adding a local weight vector to the options concerning the criteria. Finally, a vector of global preferences of decision options is determined and ordered according to the attribution of each alternative to the ultimate decision problem.

Analytical Network Process
Analytical Network Process (ANP) is the broader version of AHP (Raval et al., 2022), as the ANP can also network architectures. ANP models' components are interconnected clusters, and the components must be assessed in pairs to determine their importance. The ANP is a generalization of the AHP (Görener, 2012) since many problems cannot be structured hierarchically because they include interaction and dependence of higher-level elements in a hierarchy on lower-level elements.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
TOPSIS stands for Technique for Order Preference by Similarity to Ideal Solution (Uzun et al., 2021). With this method, the alternative closest to the positive ideal solution and the furthest to the negative ideal solution is preferred. The positive ideal solution is a combination of the best points of each criterion, and the negative ideal solution is a combination of the worst points. To use this technique, the importance weights of the criteria should be known.

2.5.2 Key Performance Indicators in literature

KPIs of similar situations are explored in literature, focused on predictability. Moreover, a link to software KPIs is made. Search criteria for KPIs in literature are that the KPIs should be relevant to predictability, and they should be possible to apply to hardware development.

Six characteristics
To determine if a project is successful, six characteristics are important (Bancroft-Connors, 2022). Value is about meeting the customer's needs, predictability is about the ability to plan and deliver, productivity is about getting more done at the same time, quality is the lack of issues with a product, and stability indicates that the organization can maintain this pace indefinitely, and growth says if the organization is growing and learning.

Cycle time (productivity)
Cycle time refers to the total time it takes to complete a process from start to finish. This can be directly linked to throughput (Bancroft-Connors, 2022), the rate at which a process can produce or deliver outputs within a period. In this way, productivity can be measured. The shorter the cycle time, the more tasks are finished within a period.

Escaped defect rate (quality)
The escaped defect rate makes the connection between customer satisfaction and the team (Bancroft-Connors, 2022). If the defect rate is low, the customer is more likely to be satisfied. If the defect rate is high, so it breaks down a lot, the customer will not be happy with the quality of the product. This rate measures the number of problems with the product once it is delivered to the customer.

Planned-to-done ratio (predictability)
The planned-to-done ratio shows how much work the team does at the start, compared to how much they have completed at the end of the task (Bancroft-Connors, 2022). For the measure to be as accurate as possible, it is important not to add any work in the middle of the task. In that case, it is important to only take the 'done' work into consideration of what was planned vs what is added.

Happiness metric (stability)
If the happiness metric is low, the team is not satisfied, and they are likely to burn out (Bancroft-Connors, 2022). This can be measured by asking the worker what they would score their happiness. A survey can also help to get some more context with the score.

Velocity
The velocity measures how much work a team completes per iteration. It is easy to measure, but it does not take staffing, leave time, and other external events into account.

Software Key Performance Indicators
Another source (Antolic, 2008), focused on the software development process, describes multiple KPIs: Schedule adherence measures timeliness and quality of deliveries to the baseline schedule and acceptance criteria. This is calculated by finding the percentage deviation between planned and actual lead times.

$$1 - ABS(ALT - PLT)/PLT) * 100$$

In which: PLT = planned start date – planned finish date and ALT = actual finish date – planned start date

The second KPI is assignment content adherence. This measures the supplier's ability to deliver the full assignment scope by the end of the assignment. It is a percentage of completed functionality divided by the requirements (number of completed requirements/number of committed requirements) x 100. In this case, the requirements are the smallest measurable packages of functionality, such as documents, requirement specifications, implementation proposals, etc. The total number of committed requirements are the packages of functionality that are originally planned, they may be revised on change request guidelines.

The third KPI is cost adherence. This measures the supplier's ability to deliver the assignment scope within the agreed costs. This is based on the committed (baseline) costs and the expected (actual + forecast) costs. (1-(expected costs – committed costs)/committed costs) x 100.

The fourth KPI is a fault slip-through. This measures the supplier's ability to capture faults before making deliveries for integration and verification. It is assumed that the supplier conducts function testing, and integration and verification testing. (1-FT faults / all faults) x 100%Ḟaults are classified as FT or I and V based on the testing phase.

2.6 Key Performance Indicator visualization

With control tools, one can obtain feedback on planned activities and their actual evolution (Vollmann et al., 2005). They are a dynamic system that analyzes the actual operations against the plan, and therefore they generate information about the quality of operations planning (Neely, 2007), (Gunasekaran and Kobu, 2007).

Key performance indicators
Indicators can improve the general control process, and thus they ultimately improve the company's performance (Lohman et al., 2004). For an indicator to be effective, it must be associated with the evaluation of an objective, which allows monitoring the Success or failure of the objective during the process. In case of a failure, indicators can also show the potential causes of the failure (Lohman et al., 2004).

Key performance indicators are a metric that is used to quantify objectives, they indicate how good the processes are (Marziali et al., 2021). KPIs are necessary for a company that wants to improve, since you cannot control something that is not measured, and you cannot manage something that is not controlled (Kucukaltan et al., 2016). KPIs vary per company, but they mostly aim at performance improvement objectives related to work productivity, product and service quality, business profitability, deadlines, process effectiveness, lead times, resources utilization, growth, cost control, level of innovation and productivity of technological infrastructure (Sangwan, 2017). A challenge when selecting KPIs is that they are in line with the company's strategic goals (Rafele, 2004).

The SMART (Drucker, 2007) criteria are useful when choosing indicators. They refer to specific, measurable, achievable, realistic and timely. To make the interpretation of results easier, indicators can be specified on characteristics (Marziali et al., 2021). These characteristics result in the baseline level, referring to the initial measurement, the current value, representing period-by-period measurements, and a goal, so what the company wants to achieve. A traffic light rating system can be used to easily interpret the results, where green represents an expected performance, amber a worrying performance and red a worrying performance.

Knowledge-based enterprises
Knowledge-based enterprises focus on using and integrating knowledge to achieve good performance. Their resources, also called knowledge fund, are mainly focused on learning (costinel nica et al., 2021). This has an important role for the performance and intellectual-intensive processes of the company,

since they are essential for the functioning of the company and achieving the company's objectives. The four dimensions of a knowledge-based company are process (activities carried out within the company), place (boundaries of an enterprise), purpose (mission and strategy) and perspective (exploitation of knowledge).

Dashboard
A dashboard is an information management tool used for analyzing, selecting and displaying KPIs (costinel nica et al., 2021). It enables a company to monitor and enhance real-time performance, so it reduces the analyzation time. It makes it easier to view data and draw conclusions. They can also incorporate predictive analysis, determining trends and patterns, so it is useful for strategy, planning and analysis. There exist different types of dashboards, such as operational dashboards (monitor operational processes), tactical dashboards and strategic dashboards. The main features of a dashboard are synergy (visually efficient), accuracy, flexibility, accessibility and news (real time). The amplification can be done in four stages:

- Identifying problems and determining objectives
- Determining end-users and establishing a plan
- Selection or appropriate indicators
- Drawing up the dashboard

Balanced scorecard
A balanced scorecard aligns the company's vision with its activities, while evaluating its performance (costinel nica et al., 2021). It can also be used to implement a strategy and define important success factors. The main advantages are a clear image of the company, understanding strategies at all levels and continuously improving economic activity. Four perspectives are important for a balanced scorecard:

- Financial (creating value and satisfying the requirements of shareholders)
- Internal business processes (quality, productivity)
- Development and innovation
- Customer

Benchmarking
Benchmarking is a continuous systematic process of measuring outputs of processes and identifying the main sources of competitive advantage (costinel nica et al., 2021). The focus is on protecting a company from competition. There are different types of benchmarking: internal, functional, general and competitive. Internal benchmarks compare processes inside a company, functional benchmarks compare functional and work tactics in different sectors, general benchmarks identify innovative technologies, and lastly competitive benchmarks compare with similar companies on performance level.

SWOT analysis
The SWOT analysis is focused on strengths, weaknesses, opportunities and threats. This is an essential model in strategic management (Barone et al., 2010). It can help select among alternative strategies and determine a strategy's viability. A competitive advantage is recognized by matching strengths to opportunities.

Conclusion
Knowledge-based companies aim to integrate knowledge to achieve a good performance. With this knowledge, a visual overview can be made.

Before a company can monitor performance, they must choose KPIs and specific goals per KPI. These goals and the current situation can be shown in a visualization. Different types of visualizations are a dashboard, balanced-scorecard, benchmarking and a SWOT analysis. A dashboard is focused on the company's operations, while a balanced scorecard is more strategically focused. Benchmarking is focused on improving the competitive advantage, and a SWOT analysis is also focused on strategic management. These four visualization types can all be effective, but it is best to base the visualization choice on the needs and focus of the company.

2.7 Visualization approach

Sedrakyan et al. (2019) describes an approach in which first an overview is presented. Then, they propose to zoom in on interesting items, filter on interesting items, select items and groups get details (details-on-demand), and relate, in which the relationship among items is viewed. Then, the history of actions is shown, and sub-collections can be extracted. Sedrakyan et al. (2019) introduces a general rule of thumb for mapping, in terms of intended goals and possible relevant visualizations. Trends are shown in a Column or a Line, a comparison is shown in an Area, Bar, Bullet, Column, Line, or Scatter. Relationships should be visualized in a Bar, Boxplot, or Column. Finally, a composition should be shown in a Donut, Pie, Stacked Bar, or Stacked Column.

In the literature review carried out by Yigitbasioglu and Velcu (2012), it is found that tabular information leads to better decisions that involve selective tasks, and with more complex information. And, the goal they say is that the designs of graphs should have the goal to improve, and not to complicated. The dashboard should be concise, simple, and intuitive.

2.7.1 Dashboard requirements

A good visualization is described by Sedrakyan et al. (2019), as a visualization that clearly illustrates a point, is designed for the intended audience, is customized to the medium of presentation, and should generate an impression of the people who are interested in the subject, as well as raising awareness. They describe a bad visualization as difficult to interpret, unintentionally misleading, and containing boring information. An ugly visualization is described as almost impossible to interpret, inaccurate, filled with useless information, and intentionally created to mislead the audience. To guarantee success, we should be careful that a good visualization is made.

2.7.2 Design stages

Designing a dashboard goes according to different stages (Vilarinho et al., 2017). First, the current state of the company should be understood, and priorities need to be identified. Then, the dashboard requirements should be identified. After that, a template for the dashboard can be designed. Then, the existence of necessary resources needs to be assured. Finally, the dashboard can be implemented, evaluated, and improved.

3 Current situation analysis

In this chapter, the current situation of the RFE department is explored. In subsection 3.1, first, the goal of the RFE department is stated, so it is clear what needs to be achieved, answering research question 4d. Then in subsection 3.2, the aspects of quality, cost, and time are discussed, concerning predictability. These aspects are relevant since they directly impact the success and profitability of a project.

Furthermore, the management models which are currently used are discussed. These models are evaluated, and the useful aspects are summarized. Understanding these models helps to identify the strengths and limitations of the RFE department, to become more predictable.

3.1 Goals of the company and their measurability

The main goal of the company is to become more predictable. This is mainly based on costs and time, so the planned costs and time should be the same as the actual costs and time. Ideally, projects go faster than planned, but if an activity is finished sooner than planned, the next activity might not be ready yet so it does not add much value to be faster, so, this is also unpredictable. In case the next activity can be started directly, it could create a buffer that can be used to cover delays later on in the project, this could help the project to still finish in time.

To be more predictable, a visual overview is wanted, to easily see the current state of the project. In this case, decisions can be made without losing a lot of time looking for the current state, which is faster. Currently, the RFE department has dashboards, but none of these dashboards display predictability.

3.2 Quality, cost and time management at the Radar Front-end Engineering department

Thales currently uses the waterfall v model, incremental model, iterative or evolutive, and agile method (Figure 11, provided by the RFE department). The RFE department specifically used all of these models, except for the agile model, since this model is more focused on software development, and the RFE department is focused on hardware development. Apart from these models, the Capability Maturity Model Integration (CMMI) is used.

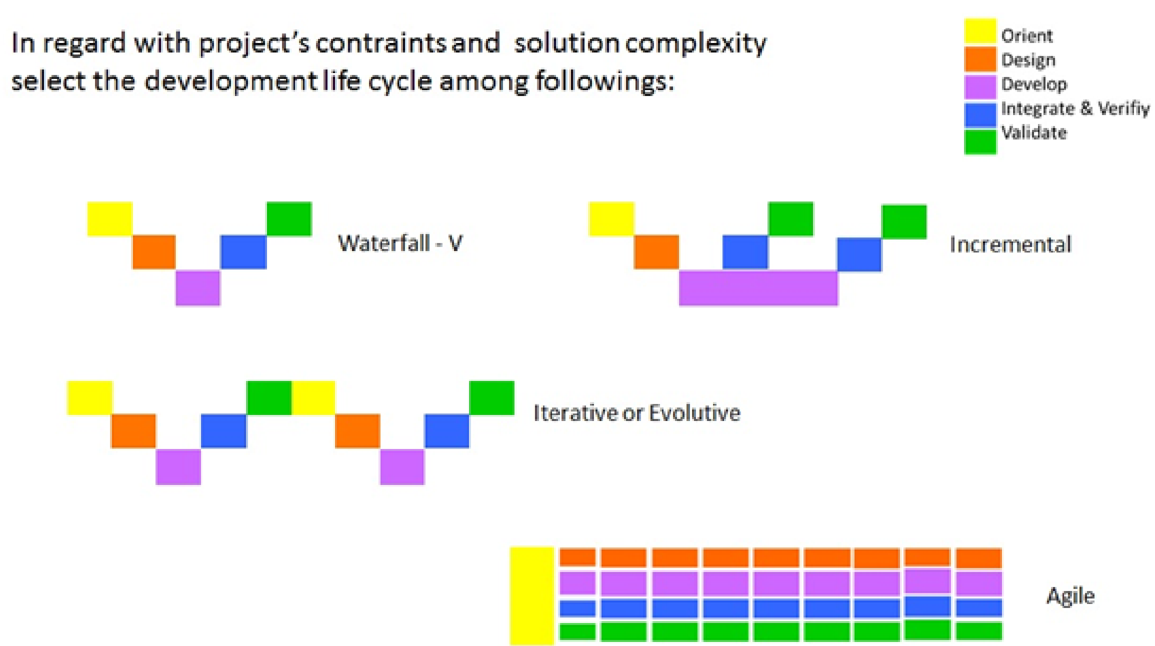


Figure 11: Thales management models This figure is retrieved from Thales' internal documents (not publicly available)

Capability Maturity Model Integration
The CMMI model can help to improve the processes within an organization. This model is also useful because Thales developed its own "CMMI" model, which is similar to the general CMMI model, but it is more adapted to the company's processes. More information on the CMMI model can be found in section 2.1.1.

V-model
Thales NL uses the V-model for the development of the complete radar system. This model is particularly relevant because of its focus on validation and verification, more information can be found in section 2.3.2. Since the RFE department works with products that should be of high quality and high reliability, this model is useful. Because of these complex products, the structured approach of the V-model helps to manage the development process.

Iterative or evolutive model
The waterfall-V model happens in multiple iterations. The first iteration usually does not result in a finished product that meets the requirements. To meet the requirements, a second iteration needs to be done, and if the requirements are not met after this iteration, a third iteration needs to be done, and so on.

Incremental model
The incremental model is mainly useful because it helps to manage the complex processes. It breaks down the complex processes into smaller increments. These increments focus on a specific aspect of a radar system. More information on the incremental model can be found in section 2.3.3.

Agile
The agile method is not used within the RFE department itself, but it is used for software engineering. All vertical blocks in the figure can be seen as circles, as is known in the agile method.

Combining the management models
These models work together by doing multiple iterations (iterative model). Then, when a first minimum viable product is ready, the integration, verification and validation will start, while still further developing the product. In this way, time can be saved, because we do not wait until the development process is completely finished, but we start testing with the minimal viable product.

3.2.1 Useful aspects of the models

From the waterfall method, a clear description of milestones and deadlines is useful, but in general, there is a big risk of delays, so it does not seem to be the optimal model in case of predictability. With lean management, the value stream map creates a good overview. However, since the goal is not only to be more predictable in costs but also in time, it is not the best option, since lean management can take a lot of iterations.

Agile allows for quick responses to changes since flexible processes are prioritized. It uses sprints, which can be used as feedback moments to see what can be improved. So, agile seems to be a suitable method, if it is adapted to hardware. Hardware development processes do not have quick deliverables, and it is hard for team members to define activities in small details, so Scrum would not be suitable for hardware development, as well as Scrumban. The visual planning of Kanban is a good thing, but in general, activities are simplified, which makes it less suitable.

4 Process and bottleneck analysis

To analyze the current development process of the RFE department, they provided a figure of the process that is now in the RFE department. The process details have been changed recently, and they are now updating all steps with more details. To get a better idea of the current process, a description for Figure 12 and Figure 13 is provided in subsection 4.1, which answers research question 2. Then, a bottleneck analysis is done (subsection 4.2), to find out more about what the possible issues on the RFE department are, which answers research question 3.

4.1 Development process

Below, the development process is shown, Figure 12 shows the left part of the development process figure, and Figure 13 shows the right part of the figure. This figure is provided by the RFE department, so it is an already existing figure. In general, the development process on the RFE department has 6 steps. These are orient, formalize requirements, design, develop, prepare integration and verification and problem integration and verification. During the Orient phase, a development plan needs to be created. To create this development plan, a Preliminary Work Package Desciption (WPDD), preliminary requirements for the product to be developed, and applicable processes – design guidelines and checklists are needed. When the development plan is created, there is a Development Orientation Review (DevOR). After the DevOR, the formalized requirements phase begins. A detailed requirement analysis is done, at the same time as the qualified supplier selection, which finishes after the design phase. During the qualified supplier selection, the feasibility and testability of the requirements are explored, and the detailed requirements and interfaces in Configuration Item Design Specification (CIDS) are documented. When the detailed requirement analysis is finished, Development Requirements Review (DevRR) is done. After this, the design phase starts with 3 parallel processes: electronics design, specialty engineering analyses, and BOM analysis key components. The last 2 need to be finished before the electronics design can be finished. During the electronics design, potential hardware architectures need to be explored, design analysis and simulations need to be performed, hardware architecture needs to be defined and established, and finally the preliminary product definition in the Engineering Bill Of Materials (EBOM) structure needs to be established. During the specialty engineering analysis, a preliminary design analysis needs to be done for reliability, maintainability, and safety. In the Bill Of Materials (BOM) analysis key components, an analysis needs to be done on the preliminary design for the component status and availability, and the termination finish.

At the beginning of the design phase, the Obsolete (OBSO) analysis and preliminary thermal analysis start. During the OBSO analysis, it is checked if products are available, stay available, and if necessary, build up an inventory. Preliminary thermal analysis is needed to finish the electronics design. When the Development Preliminary Design Review (DevPDR) has been finished, the development phase can be started. This starts with a schematic design, BOM analysis, preliminary pinning FPGA, and the OBSO analysis is still not finished. The BOM analysis and Preliminary pinning FPGA need to be finished to finish the schematic design. During the schematic design, a detailed design analysis and simulations are done. Then the detailed design of the product is defined and established, then the PCB-design constraints in Programmable Database (PDB), Pre-Layout Instruction (PLI) are defined and established, including Printed Circuit Assembly (PCA)/Printed Circuit Board (PCB) technology constraints or classes. Finally, the BOM analysis of all components is performed. During the preliminary pinning FPGA, the FPGA selections are established and the preliminary pinning for FPGA is defined. When all this is finished, a schematic and BOM review is done. Now, in parallel, two process flows are executed. On top, it starts with layout orientation, during this phase, the PCB layout approach is explored, and the PCB layout approach and planning in the development plan is established. Then the layout kick-off is done, after which the PCB technology is selected. This is followed by a tech review. Then the placement of components takes place, for this, the component placement and critical routing are explored, and the main component placement and critical routing are established. At the same time, models and drawings of PCA and PCB are created, which are finished when the routing is finished. After the placement, a placement review is done. Then, the routing of signals on PCB is performed and established, and component placement, outline, and mechanical interfaces are finalized.

When the placement is halfway, PDB is created, and the Signal Integrity/Power Integrity (SI/PI) is performed. Simulation models for SI/PI are created, SI/PI analysis for products are performed, and PCB layout instructions and constraints (PLI) are updated. After both processes, a Technical Product Documentation Review (TPDR) is done. After the placement review, an update of the FPGA pinning is done. After the route is finished, the Technical Product Documentation (TPD) can be finalized. Finally, the TPDR is done.

At the same time, a mechanical orientation is done, in which the mechanical design approach is explored, and the mechanical design approach and planning in DP is established. This is followed by a mech kick-off. Then the mechanical models and drawings of board-related parts are created, and the process is finished with a TPDR. Now a Development Critical Item Design Review (DevCDR) is done, followed by finalizing product definition. Then the product definition needs to be ready.

Now, the process of preparing the integration and verification starts. During this process, the Configuration Item Test Specification (CITS) needs to be clarified, and the setup verification needs to be prepared. After this phase, a Development Test Readiness Review (DevTRR) is done, in which everything that is needed for testing is gathered. Then the integration and verification can be performed. Tests are performed, CITS is updated, and the PDB is updated. When these are all finished, a Development Technical Qualification Review (DevTQR) is done, where it is proved that the requirements are met. After that, the life-cycle transition review is performed, in which is determined how mature a design is.

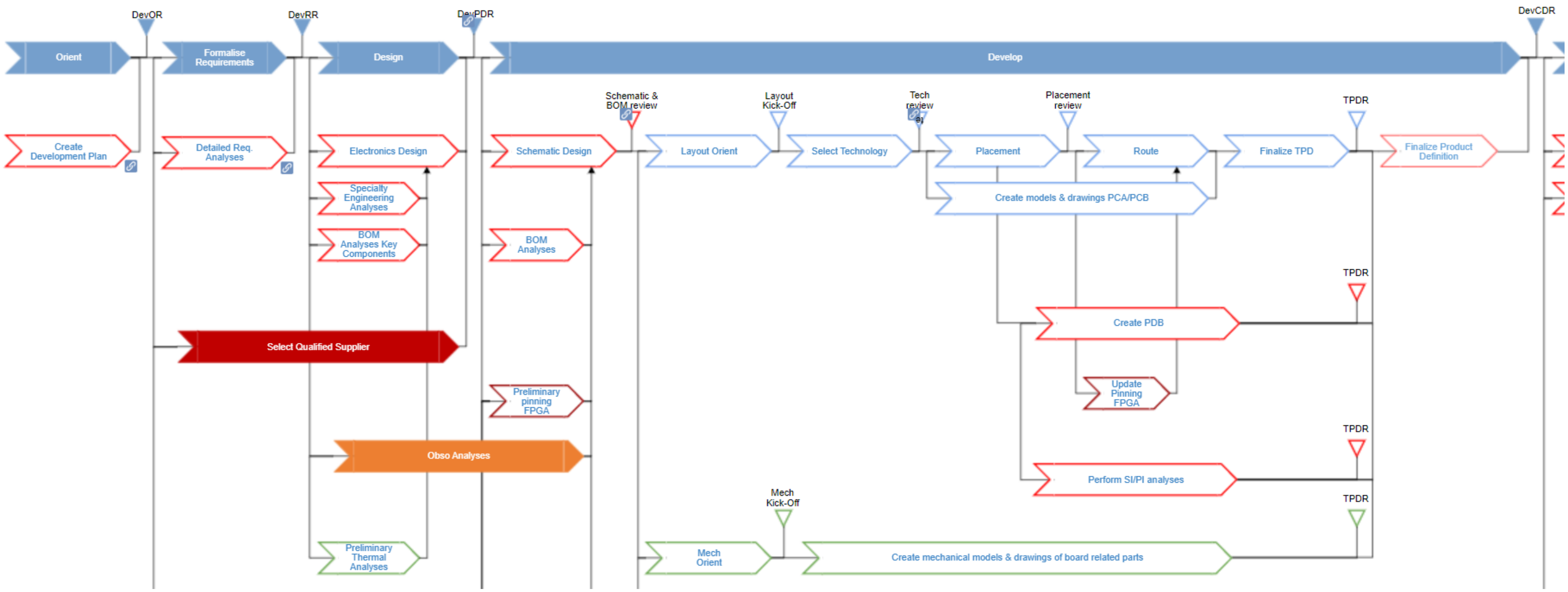


Figure 12: Process flow RFE department. This figure is retrieved from Thales' internal documents (not publicly available)

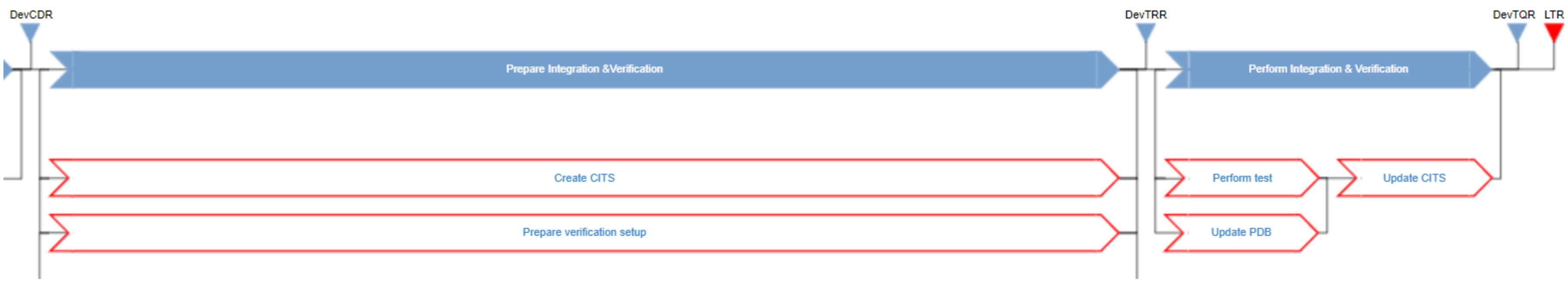


Figure 13: Process flow RFE department continued from Figure 12. This figure is retrieved from Thales' internal documents (not publicly available)

4.2 Bottlenecks

To find out more about the bottlenecks in the development process, 4 semi-structured interviews were conducted with Work Package Manager (WPM)s and with someone who works with the departments KPIs. These interviews lasted between 1 and 1.5 hours, the first interviews took longer, since the questions were new. Later interviews were a little shorter since most answers were similar to those in earlier interviews, which is also why not more interviews were conducted. The interview structure and questions can be found in subsection H (Appendix H). These questions were used as a guideline, but depending on the interviewee's answers, follow-up questions are asked, and irrelevant parts can be skipped. This chapter is split up into the overarching topics that were discussed during the interviews. It was chosen to use an interviewing approach to define bottlenecks because the mathematical approach could not be used because of a lack of available data

4.2.1 Suppliers

From the interviews, it became clear that one of the reasons why the RFE department is not predictable, is the predictability of other companies. In general, over the last few years, the lead time of materials has increased significantly. A lot of components take over a year to arrive, so a decision to buy certain components needs to be made over a year before the component is needed. If the lead times go up significantly this year, you might still be too late, because for example it now takes 2 years to arrive. In that case, you have a whole year of delay, depending on the importance and dependencies of these components. Sometimes, when there are signs that a component is not going to be on the market in the future, they stock up on components

Another issue with suppliers is the communication process. Sometimes the suppliers claim they can make something, while in reality, they are not capable, or it takes much longer. Sometimes they do not follow the whole process, and not all inputs are there. This may cause them to think it is less complicated than it is. Another side to this story is the lack of a critical attitude by the RFE department, which is mentioned during an interview with a WPM. However, Thales undergoes a thorough qualification program for suppliers before a hardware production contract is signed. Moreover, a supplier is invited to design reviews where they can assess their ability to produce the hardware. To further improve this selection process, they could test the supplier more before signing a contract, and for example, ask for proof that they can do a certain action. Also, suppliers have main customers, and another customer may be more important because they are a bigger customer and pay more. This may cause prioritization and therefore sometimes a delay for the RFE department of Thales.

4.2.2 Multiple iterations

To be predictable, you need to estimate how many iterations are needed to finally deliver the product to the customer. Every extra iteration takes a lot of time and money, depending on the complexity of the issue. To give an example, having to redo something in the PCA process usually takes 9 months to a year, and a mechanical issue usually takes around half a year, depending on the lead times of components.

An extra iteration is needed in case there is an issue, so something is not working as it should, or in case of extra, or adjusted requirements. Usually, if a product is almost ready, they want to finish the project, and they settle for less. This means that components that were first classified as less good, can now be good enough to be used. This happens because it takes a lot more extra time and money to throw something away and start a completely new iteration. You could also say that the specifications of the product were too high, to begin with, if it is good enough to be used in the end.

Something that can help to do fewer iterations is accepting that good is good enough. If the requirements are met, and it is producible, it works and it is not necessary to do more work to make it better. Also, when requirements are adjusted or added, it can be critically reviewed if it is possible and necessary, and if it will change the costs and planning too much.

4.2.3 Knowledge

As mentioned before, during the interviews the topic of experience came up a lot. It was mentioned by all people, so it is a topic of interest. Because the development process of a New Product Introduction is so complicated, it takes a lot of time to learn and to become experienced. Since the whole development process can take around 10 years, employees do not get to experience the same things over and over again in just a few months. This means that the "inexperienced employee" phase can take quite long compared to a job in which you do the same activities over and over again. Two people with the same function description also do not necessarily have the same knowledge at the RFE department, which makes it harder to work together if it is not clear who knows what. People that have less knowledge of the systems, usually make a less accurate prediction. They do not always know if all necessary aspects are taken into account, and they have less knowledge of risks.

To make sure the planning of inexperienced employees is as good as possible, their development plans will be discussed with someone with an expert opinion. It will be checked if all necessary elements are taken into account.

4.2.4 Overview

Some engineers focus more on the details of a subarea, and they do not think about the whole picture and the effect they have on the bigger picture. Sometimes, an insecurity or uncertainty is passed onto the next person, so they do not have to deal with it, which is not optimal for the project. It can help to sometimes have a more simplified look over the project, the main focus is on complicated processes. This means that a standard approach for relatively simple issues is lacking, and the translation of abstract requirements to the practical approach is missing. Moreover, sometimes contracts are signed, while the agreement is unrealistic. In this case, the planning has to be adjusted as soon as is known that the deadline is unrealistic.

4.2.5 Flow of activities

According to WPMs, a lot of time gets lost at the transfer moment from one activity to the next activity. Some people only start looking at what needs to happen to start the next activity once the first one is finished. This causes a lot of unnecessary delays. So, the integration and tuning of activities can be better.

5 Key Performance Indicator (KPI) selection and implementation

In subsection 5.1, a conclusion is drawn on the selection criteria, based on the literature review done in subsection 2.5, answering research question 4b. In subsection 5.2, a conclusion on a suitable KPI selection method is drawn based on the literature review in subsubsection 2.5.1, answering research question 4c. This technique is not directly used in this research, but this advice can be used for further KPI selection in the future. In subsection 5.3, the KPIs that are currently used by the RFE department are discussed. The relevancy (subsubsection 5.3.1), and reliability (subsubsection 5.3.2) of the current KPIs are also discussed. In subsection 5.4, all relevant KPIs are shown, combining the KPIs that are currently used and newly added KPIs. subsection 5.3 and subsubsection 5.3.1 together answer research question 1b. subsubsection 5.3.2 answers research question 1c. In subsection 5.5, an overview of these KPIs is given, which answers research question 4e.

5.1 Selection criteria

In subsection 2.5, a literature review on KPI selection criteria is done. Based on this literature review, we can set our selection criteria.

The KPIs for the RFE department have to be SMART: specific, measurable, achievable, relevant, and time-bound. Moreover, they should be operational and functional with a focus on process performance. This all together ensures clear objectives, measurable outcomes, and realistic goals.

5.2 KPI selection techniques

Comparing the methods mentioned in subsubsection 2.5.1, AHP is the recommended technique to use when selecting KPIs. This method has a broad orientation phase, which is good when you want to measure something new. Moreover, ANP and AHP are focused on pairwise assessment, which is not possible when you want to start selecting KPIs from scratch, and pairs are not yet possible. TOPSIS could be an alternative solution, but it is less ideal since the weighting is subjective, so with this technique, the outcome is very unreliable when selecting KPIs from scratch.

5.3 Key Performance Indicators currently used

In the Table 2, the current KPIs are shown. The measurement, goal, and value of each KPI is shown, for confidentiality reasons, the average value is multiplied by a random number. For all average values this is the same random number. These KPIs are their goals are set by the management team.

Table 3 shows the other KPIs for which a goal is defined. There is some overlap between this table and the table above, but sometimes the name is different. CDR $\rightarrow$ PDP is the design release in the table above. PDP $\rightarrow$ PCB ready is the same as PCB production cycle time, and PRR $\rightarrow$ PCB ready is the same as PCB production. This is similar to PCA production.

5.3.1 Relevancy of the current Key Performance Indicators

RFQ PCA $\rightarrow$ PO PCA is not relevant to determine the predictability, since it indicates the communication times with a supplier (Benchmark). The rest of the KPIs are all relevant to some extent. The design release is for example indirectly important because if the requirements are not clear in the beginning, it takes more time in the PRR. Then they will mention what is missing during the Production Readiness Review (PRR), while it could have been there if it had been mentioned before.

5.3.2 Reliability of the current Key Performance Indicators

The KPIs, and therefore the predictions are not reliable. There is a central data system for Thales, but it is not detailed enough for the RFE department to be useful regarding predictability. There is no central data system used to calculate the local KPIs for the RFE department. Therefore, the right information must be gathered every month before the KPIs can be calculated by hand. There are many documents and information available, but this information is not correct or relevant. It would

Table 2: KPIs currently used. This information is retrieved from Thales' internal documents (not publicly available

KPIs	What does it measure?	Average value (days, including weekend days), multiplied by a random number	Goal (days, including weekend days)
Planning accuracy (on-going, initial to actual)	How accurate the planning is, so how much the finishing date differs from the scheduled date	142.5	0
Design release	When the design can be released	115	14
PCB production cycle time	The time it takes to complete the production of PCB	322.5	56
PCB production	The time it takes to go from PRR to the PCB being ready	210	40
Avg PDP approved to PRR	Average days it takes to get the PDP approved for PRR	112.5	-
RFQ PCA → PO PCA	Estimated to be a realistic time; 4 wk for proposal 2 wk for PO	172.5	42
PCA production cycle time	The time it takes to complete the production of PCA	197.5	49
PCA production	The time it takes to go from PRR to the PCA being ready	177.5	28
Avg PCB ready to PRR	Average time it takes to get the PCB ready for PRR	20	-

Table 3: KPIs and goal methodology. This information is retrieved from Thales' internal documents (not publicly available

KPIs	How was the goal established?	Goal
Planning accuracy (ongoing, initial to actual)	Time between initially planned and actual CDR	0
CDR → PDP released	Internal goal	14
PDP released → PCB ready	GCC estimated 6-8 weeks for production of a medium complexity	56
PRR → PCB ready	GCC estimated 6-8 weeks for production of a medium complexity	40
RFQ PCA → PO PCA	Estimated to be a realistic time; 4 weeks for proposal 2 weeks for PO	42
PCB ready → PCA ready	(FAI from GCC is 3 weeks) Benchmark estimated 28 days for a medium complexity PCA	49
PRR → PCA ready	Benchmark estimated 28 days for a medium complexity PCA	28

be good to create a central database, in which employees only must enter certain information. Based on this database the KPIs can be calculated, and it would be much more reliable.

5.4 Relevant Key Performance Indicators for the RFE department

There is a difference between relevancy for management and relevancy for engineers, which is mentioned during one of the interviews, since engineers are more focused on specific parts of the project, and the management team has a better overview of the whole project. For everyone, it would be relevant to know what products are being developed now. To add, it is good to also show how far along the development process is, for example by showing the last achieved milestone. It could also be interesting to show how long a certain step in the process takes on average, including delivery times.

To be more predictable, it is important to bridge the gap between management and engineers. If engineers know why they have to make a plan, and what the consequences can be, they can get more motivated to do it. If they make a plan because they have to, it leads to inaccurate numbers, because they must enter a certain number of hours in the planning, which can take much longer or shorter in reality. Therefore, it could help to make the management issues more known, and for example, show average deviations from reality. This would address the importance of making accurate plans.

During the literature review on KPIs, in subsubsection 2.5.2, KPIs in literature are explored. The focus on this study was on KPIs in predictability, preferably in hardware, but some software KPIs could also be used if they are critically reviewed.

The first chosen KPI is cycle time per phase, so orient, design, develop phase, etc. This indicates how long each phase takes per project. It does not directly show the predictability, but when enough data is gathered, an analysis of similar projects can be done. The second KPI is the planned-to-done ratio. This shows how much the team has completed at the end of a task. There should be a protocol that shows how to handle work that is added later, to avoid unusable results.

The third KPI is schedule adherence, which measures the timeliness and quality of deliveries to the baseline schedule and acceptance criteria. This is complicated to measure, so it is best to do this calculation for each activity, and then review if it is valuable.

The fourth KPI is supplier delivery adherence, which measures the ability of the supplier to deliver the full assignment scope at the end of the assignment. This helps to critically review the performance of suppliers, which can lead to selecting more reliable suppliers.

The fifth KPI is cost adherence. This is also focused on the supplier, and it is similar to the fourth KPI, but with a focus on costs. So, it measures the ability of the supplier to deliver according to the agreed costs. The sixth KPI is fault slip through. This is also focused on supplier reliability, and it helps to determine the quality of work of the supplier.

Moreover, 8 out of 9 existing KPIs can be relevant (read section 5.4.1). They are not that reliable yet, because of the lack of data, but when more data is gathered, these KPIs become more reliable and valuable. Figure 14 shows a graph with the relevant KPI values, and their goal. This graph was made to have a visual overview of the current KPIs.

The planning accuracy has a goal of 0, but within 5 days is also good enough, so therefore the adjusted goal was also shown. Figure 14 shows that all KPIs are much higher than their goal, and most of the KPIs are even more than twice as big. Please keep in mind that due to confidentiality reasons, the average values are multiplied by a random number.

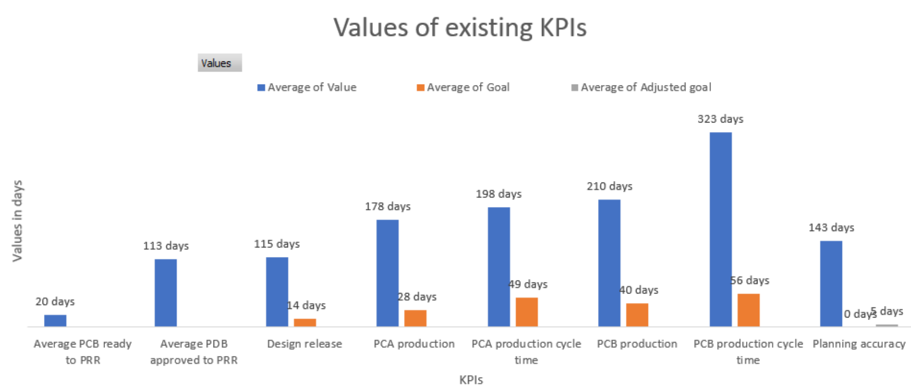


Figure 14: KPIs

5.5 Overview of chosen KPIs

In Table 4, an overview of the chosen KPIs can be found. This table includes current, and newly suggested KPIs. The meaning, calculation and visualization method are given. For the existing KPIs, there is no calculation provided, since this can be deducted from the development phases. During the interview it became clear that there is not one clear standardized method that is used to calculate the KPIs, so it is not possible to formulate a calculation for these KPIs.

Table 4: Overview of chosen KPIs

KPIs	Meaning	Calculation	Visualization
Planning accuracy (ongoing, initial to actual)	How accurate the planning is, so how much the finishing date differ from the scheduled date	-	Bar chart
Design release	When the design can be released	-	Bar chart
PCB production cycle time	The time it takes to complete the production of PCB	-	Bar chart
PCB production	The time it takes to go from PRR to the PCB being ready	-	Bar chart
Avg PDP approved to PRR	Average days it takes to get the PDP approved for PRR	-	Bar chart
PCA production cycle time	The time it takes to complete the production of PCA	-	Bar chart
PCA production	The time it takes to go from PRR to the PCA being ready	-	Bar chart
Avg PCB ready to PRR	Average time it takes to get the PCB ready for PRR	-	Bar chart
Cycle time per phase	Indicates how long each phase in the project takes	Sum of (end date of phase minus start date of phase) divided by the number of phases	Bar chart
Planned to done ratio	Shows how much the team has completed at the end of a task	Number of completed tasks divided by the number of planned tasks	Pie chart
Schedule adherence	Measures timeliness and quality of deliveries	Number of tasks completed on time divided by the total number of tasks	Line chart
Supplier delivery adherence	Measures the ability of the supplier to deliver the full scope at the end of the assignment	Number of requirements met divided by the number of requirements, multiplied by 100	Pie chart
Cost adherence	Measures the ability of the supplier to deliver within costs	Actual costs divided by the Planned costs (supplier)	Bar chart
Fault slip through	Helps to determine the quality of work of the supplier	Number of defects found after phase divided by the total number of defects (supplier)	Line chart

6 Visualization of predictability

In this chapter, the visualization strategy is described in subsection 6.1, based on the literature review in subsection 2.7. In subsection 6.2 the design process of the dashboard is described, showing a summary of what the dashboard should include. Together, subsection 6.1 and subsection 6.2 answer research question 5. In subsection 6.3, calculations are made to show a general overview of the current performance of the RFE department, concerning predictability. In subsection 6.4, more detailed calculations are made regarding the current state of predictability. subsection 6.5, the reliability of the current predictions is discussed. In subsection 6.6, the outcome of the dashboard design is presented. Finally, in subsection 6.7, the dashboard design is reviewed, to check if it meets the goals and expectations of the RFE department, which answers research question 6.

6.1 Visualization strategy

Based on the systematic literature review, a decision of strategy for visualizing KPIs can be made. Since KPIs can be used for monitoring the success or failure of an objective during a process, first KPIs need to be selected. This will be done in research question 5: "What is an effective way to visualize the KPIs to give more insight into the performance and predictability?".

After the KPIs are selected, a visualization of these KPIs must be developed to easily monitor them. The goal is to see within one view what the current state of the processes is. Before developing a visualization, a visualization method needs to be chosen. In the systematic literature review, multiple methods are mentioned, namely a dashboard, a balanced scorecard, benchmarking, and a SWOT analysis.

An operational dashboard is the most suitable option since it is used for analyzing, selecting, and displaying KPIs, focused on operational processes. It monitors real-time performance, so it is easy to conclude this visual overview. It is also possible to do a predictive analysis and determine trends and patterns from a dashboard, which helps the RFE department to get more predictable.

A balanced scorecard evaluates the RFE department's performance, but it is more focused on implementing a strategy, compared to a dashboard. Since the core problem does not have anything to do with implementing strategies, this option is not suitable.

Benchmarking is a continuous systematic process of measuring the outputs of processes, and its focus is on protecting the company from the competition. The core problem is not just focused on measuring outputs, but also on what the outputs mean and what the consequence of an output is, so benchmarking does not cover the full goal of solving the core problem. Moreover, the core problem does not have anything to do with competition.

A SWOT analysis is focused on defining the strengths, weaknesses, opportunities, and threats. It is essential for strategic management, which is not relevant in this case. Although a SWOT analysis is not a suitable visualization method, finding strengths, weaknesses, and opportunities could help to define the current situation. So, a full SWOT analysis is not useful, but certain parts could be used to answer research question 1: "What does the current situation of the Radar Front-End engineering department look like, focused on lead times and costs?".

So, to visualize KPIs and get more information on the performance of development processes, a dashboard will be developed.

6.2 Dashboard design process

In subsection 6.4 the method of calculating the current predictability of 10 development plans is described. These development plans can be used as a base for the dashboard design. From the calculations, charts can be made.

Key Performance Indicators on the dashboard

A layout of the KPIs on the dashboard will be made. Advice on a KPI selection method is given, and a selection of KPIs is made based on the literature review. However, it is not within the scope of the assignment to run through the whole KPI selection process, including extensive stakeholder identification, and weighting criteria. For the existing KPIs there is not one clear method, and it is manually calculated so it is not possible to include the calculation in the document for now. Therefore, only a layout of KPI will be given, and the RFE department can include their further calculations of KPIs in the dashboard. Hopefully, in the future, the KPI calculation can be done in the same document, and therefore easily be included in the dashboard. A summary of the dashboard is given in Table 5.

Table 5: Dashboard summary

Purpose	Users	Features	Criteria
• Monitor projects, taking the targets into account • Problem identification, information analysis • Improve decision-making and overall performance	• WPMs: how is their planning going? • Head of department: how is the department doing overall, focused on predictability? • Team managers: How is their team functioning? Does everything go according to plan?	• Excel dashboard, using VBA to allow for easy use • Monitor project planning and predictability • Monitor KPIs • Monitor milestones	• Information presented simply and appealingly to ensure understanding • Designed for the intended audience • Should raise awareness for the target audience

6.3 General overview calculations

There is not a clear measurement for the predictability yet, on the RFE department. Within each project, the engineers make a personal development plan, and these plans are combined into one big master schedule. The WPM and the team manager track the status of the activities in the development plans. Recently, a new format of the development plan has been introduced, which keeps track of the actual plan. A start- and end date can be filled in, as well as the plan (budget hours), actual time, costs to come, and percentage complete. With this information, the earned after completion, the difference between hours planned vs. actual, and average burn is calculated. Percentage complete and difference in hours planned vs. actual is measuring the predictability, but an issue is that the difference in hours planned vs. actual is only filled in after the activity is finished.

In Figure 15, the sum of the plan (budget) sum of the actual value, the sum of the Cost to come (CTC), and the sum of the Estimate At Completion (EAC) are shown per project assembly. Each project assembly is part of a project since projects consist of multiple assemblies. In this graph, it can be seen that PCA_10 has way higher values than all other assemblies. High Actual value (ACT) can be caused by for example unforeseen circumstances, or inefficiencies. A high planned budget indicates that the assembly is more complex, or bigger than the other assemblies. Compared to the other values, the CTC for PCA_1 is relatively low, which indicates that there are not a lot of complex, expensive tasks left. Finally, the EAC is the sum of the ACT and CTC, so with the actual value being high, the EAC will also be high.

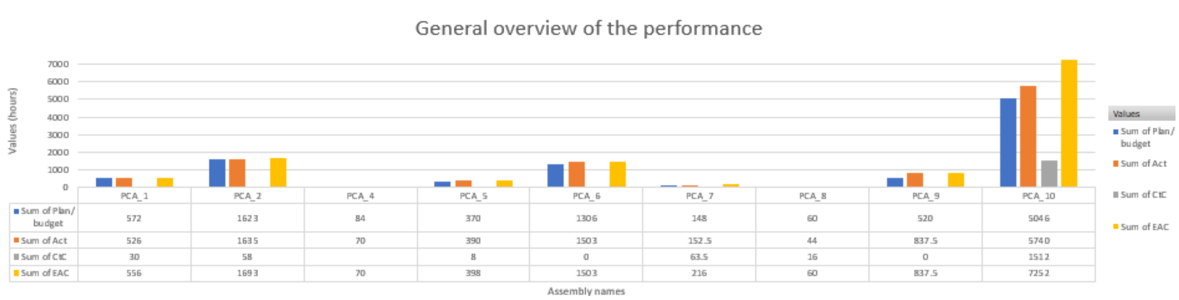


Figure 15: General overview of the performance

Figure 16 shows the cost that still needs to be made. This is also shown in Figure 15, but in Figure 16 the number and differences are better readable. It is noticeable that the assembly on the bottom still needs a lot of work, but the second, third, and eight assemblies do not expect any more cost to come.

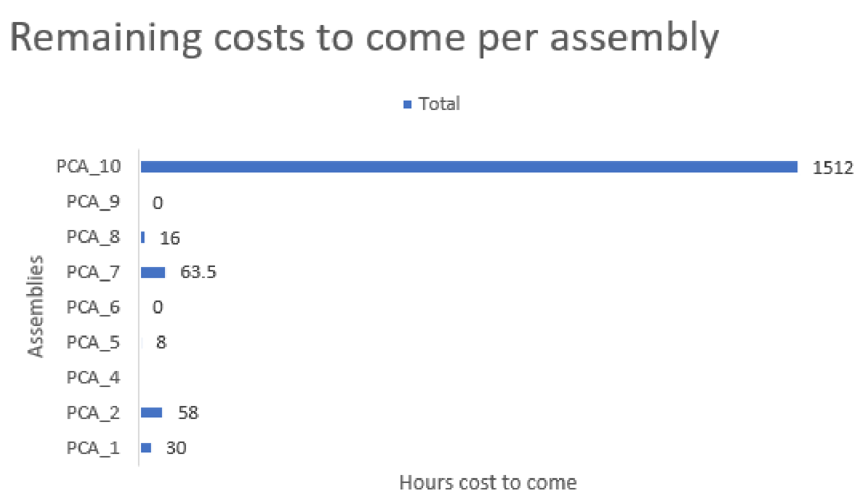
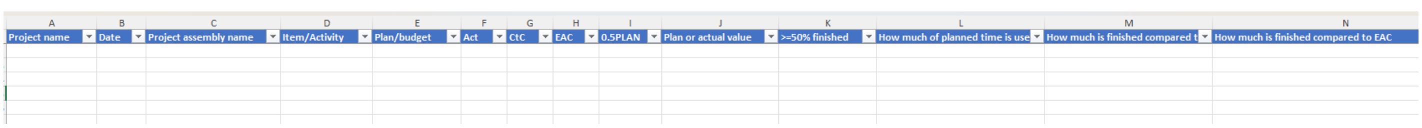


Figure 16: Hours of cost to come per assembly

6.4 Calculation of the current state of predictability

To be able to say something about predictability, a data analysis has to be done, therefore, development plans are analyzed. In these development plans, a planning of a specific part of a project is done. So the development plan of Engineer X shows all the tasks that Engineer X has to do. The WPM combines the plans of all engineers, to make a master schedule. Ideally, you would analyze this to be able to say something about the predictability of a complete project. However, a lot of data is missing, and the accuracy of the numbers in these development plans is debatable. Therefore, we start with analyzing 10 development plans of engineers, and later the same method and calculations could be done to the master schedules.

To do the data analysis, the time planning of all 10 DPs is put together in one big table on an Excel sheet (Figure 17). This table has column names "Project name", "'Date", "Project assembly name", "Item/Activity", "Plan/budget", "ACT", "CTC" and "EAC", which have to be filled in. The planned or budget is the number of hours that are planned to spend on an activity, "Act" stands for actual, which indicates how many hours are spent on the activity so far, and "CTC" stands for Costs to Come, indicating how much hours are needed to finish the activity. EAC stands for estimate at completion, and it displays the new expected number needed in total, to finish an activity.



A	B	C	D	E	F	G	H	I	J	K	L	M	N
Project name	Date	Project assembly name	Item/Activity	Plan/budget	Act	CtC	EAC	0.5PLAN	Plan or actual value	>=50% finished	How much of planned time is use	How much is finished compared t	How much is finished compared to EAC

Figure 17: Excel sheet "Useful data"

In column 9, half of the plan is calculated (0.5*plan), which is needed for later calculations. Then, a VBA script (Listing 1) is written which is first checked if the values in the cells of the column "Plan/budget", "ACT" or "EAC" are empty. In case it is empty, calculations cannot be made, and "Empty" is displayed in the 10th column, named "Plan or actual value".

In case the 10th column is empty (so it does not display the word 'empty'), the needed data is there, and a calculation can be made. If the word 'empty' is shown, critical data is missing and calculations cannot be made. We want to make sure the data that is written down makes sense since it does not make sense to say something about predictability if activities have not started yet. In that case, it has not changed so the degree of predictability of that activity also has not changed yet. Therefore, it is calculated if the activity is halfway finished or more, with "Act $\geq$ HalfPlan". If this is true, in column 11 ("$\geq$ 50% finished"), "Yes" is displayed, if it is not true, cells are left empty. Figure 18 shows how many of the tasks are over 50% complete, and therefore it shows how many usable data entries each assembly has. Now the actual calculations of predictability can be started. We first calculate how much of the planned time is used until now (column 12). It is checked if the activity is halfway or

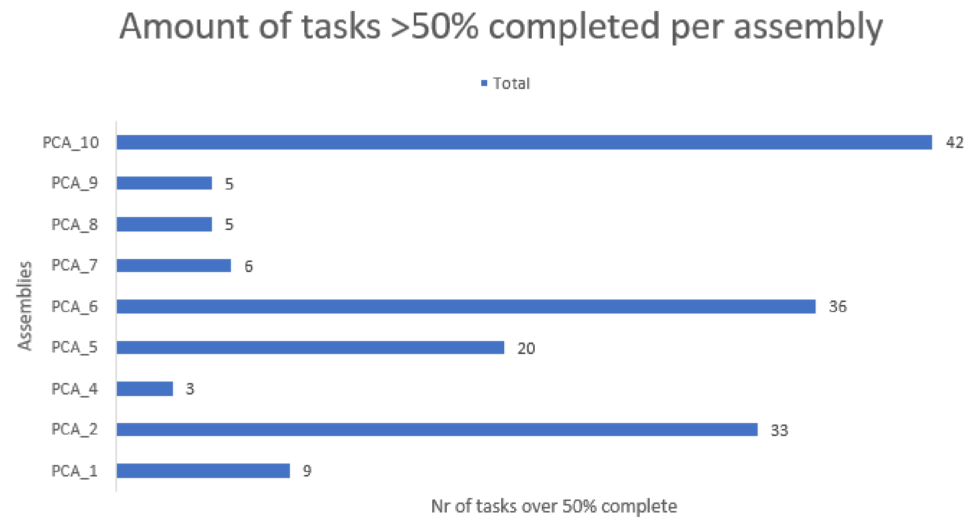


Figure 18: Number of tasks that are over 50% complete, per assembly

more, and the planned value is not zero. If this is true, the EAC value is divided by the planned value, and this number is displayed in column 12. In case the numbers are not there, "NA" is displayed in column 12, and we can not conclude their activities. Figure 19 shows the graph of the planned time in hours that have been used until now. The assemblies that are over 100%, definitely take longer than planned. The assemblies that are lower than 100% have a possibility of being finished before the planned time, or according to plan, the EAC is lower than what was originally planned.

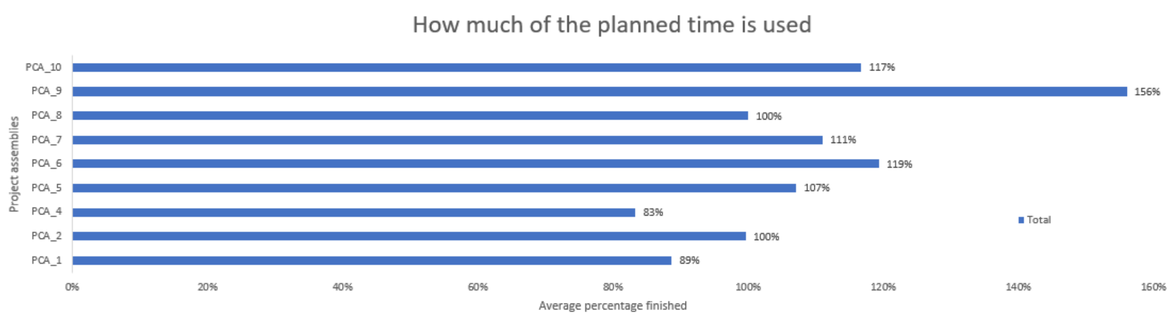


Figure 19: Percentage of planned time used per assembly

For the second predictability calculation, we check how much of the activity is finished compared to the planned value. So, we check if we are on schedule by dividing the actual value by the planned value. Again, under the condition that 50 percent or more is finished, and the planned value is not zero. The calculated number is displayed in column 13, and if the conditions are not met and therefore a calculation cannot be made, "NA" is displayed. This variable is displayed in Figure 20. If the value is more than 100%, more work is finished, compared to what should have been finished at this point, according to plan, so you are ahead of plan. A value lower than 100% then means that you are behind schedule.

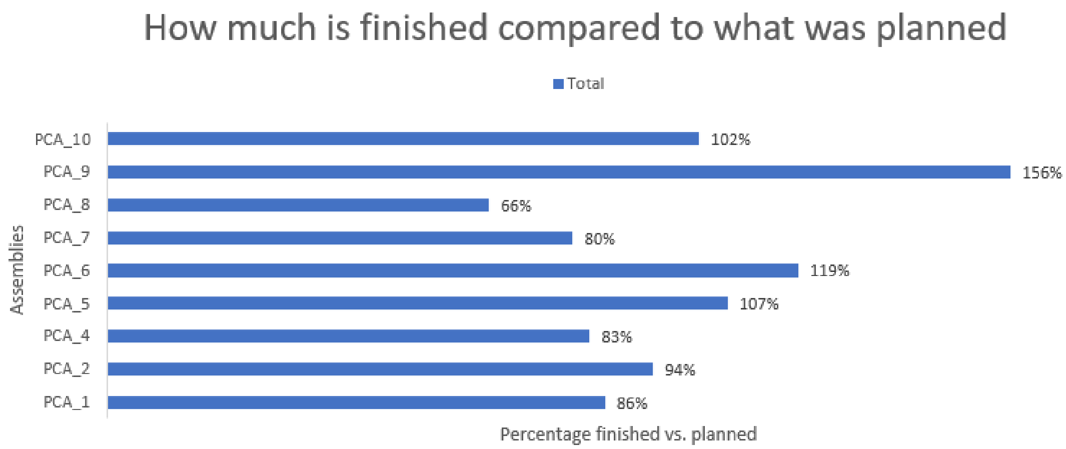


Figure 20: Percentage of how much is finished compared to what is planned

The final calculation we do is checking how much has finished compared to the EAC. Again, under the condition that 50 percent or more has been finished, and the planned value is not zero, the actual value is divided by the EAC. The calculated number is displayed in column 14, and if a calculation cannot be made, "NA" is displayed. Figure 21 shows the comparison between the amount of work done and the EAC. A value greater than 100% means you did more work, compared to what was estimated, so the project is either more efficient, or the EAC estimation was too high. A value lower than 100% means you are behind, so less work is done compared to what is expected. In this case, the EAC could have been unrealistic, or the work was carried out inefficiently.

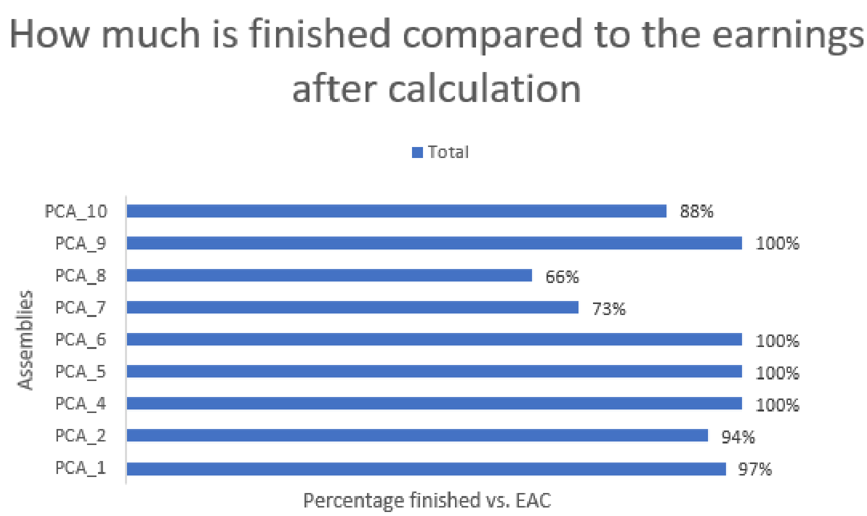


Figure 21: Percentage of what is finished compared to the estimate at completion (EAC)

6.5 Reliability of the current predictions

From interviews with WPMs, it can be concluded that predictions are not always that reliable. The reliability of predictions is dependent on a few factors. The degree of experience of the engineer plays a big factor. There is not one clear guideline when it comes to project planning within the RFE department. A lot of decisions are made based on experience, so when an inexperienced engineer does the project planning, the planning is likely to be less reliable.

Another aspect that affects the reliability of the predictions is the complexity of the project. A more complex project is more complicated to finish within the scheduled time and costs because more unforeseen circumstances occur. With a complicated project, sometimes it is important to just be 'good enough', to meet the specifications, because doing more costs more time and money.

Another aspect is the reliability of the initial development plan of engineers. Not everyone takes the development plan seriously. Sometimes they fill in what they think the WPM wants to see, while this is not always the real estimate. In this case, it is likely to take longer than expected, but it is not calculated beforehand so the prediction was not accurate. In the analyzed development plan it was also an issue that a lot of boxes are empty, and therefore information is missing to keep track of the current state.

For the predictability to be reliable, data should be analyzed to find a pattern. However, the data given by the RFE department is not reliable, since there are a lot of unusable data entries, as can be seen in Figure 22. Of the ten development plans that were analyzed, nine had more unusable data than usable data. Unusable data means that no numbers are added to a specific task, or one of the critical data entries is empty. The essential data entries for the predictability calculation are the planned budget, actual budget, and actual value. Without these values, no calculations can be made, and thus the data entry is unusable. If additional data had been provided later on, it could still be useful.

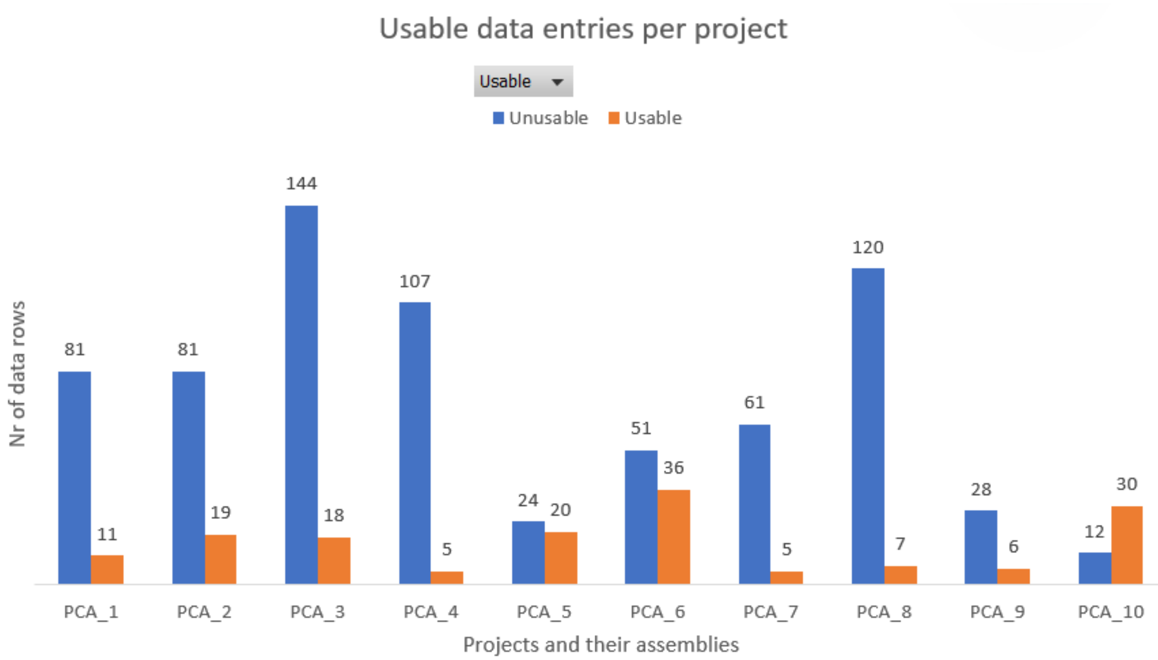


Figure 22: Usable data entries

6.6 Dashboard design outcome

General information

The dashboard (Figure 23 and Figure 24) shows a variation of charts, a milestone table, and a KPI chart. For easy use, a control panel for the charts is placed at the top of the dashboard. This control panel shows a button to refresh the date to today's date, a button to refresh all pivot tables and pivot charts, and a button to refresh the milestones table. Next to that, slicers are added. The left one called "Project name", filters on the project name, and the middle one, called "project assembly name' filters on the project assembly name, which is a level lower since multiple assemblies are part of a project. Both of these slicers work for the graphs in the "Data visialization" area, for the general overview graph. So, when using this slicer, you can get the whole dashboard to give information about a specific part of the project. The right slicer is focused on KPIs, and a specific KPI can be selected.

On the right of the dashboard, a navigation center is located. Within this navigation center, multiple divisions are made, called "Data sheets", which lead to specific sheets with data, "General overview and KPI sheets", which lead to the sheet with the general overview pivot table and pivot chart. Next to that, the "Data visualizations sheets" refer to sheets with information about the earned value analysis, cost to come, percentage of planned time used, and finally project completion status. The last button refers to the milestones sheet.

General overview and KPIs

The dashboard's information is divided into three parts: ”General overview and KPIs”, ”Data visualization” and ”Upcoming milestones within the next year”. The general overview graph shows an overview of all project assemblies, and their sum of plan/budget, sum of actuals, sum of costs to come, and the estimate at completion. For clarity, it is chosen to display the numbers of each category in the table below the bars in the graph. The graph ”KPI values” shows the KPIs that are considered relevant in subsection 5.4, and for which data is known. A recommendation of more KPIs is done, however, these are not included yet in the dashboard, because the necessary data and calculations are not available yet, and it is beyond the scope of this assignment to calculate the new KPIs. To improve this dashboard, and include the recommended KPIs, the sheet called KPIs can be opened, and then new KPIs and their value, goal, and possibly adjusted goal can be inserted in the table. Then, when clicking the ”Refresh all Pivot Tables and Pivot Charts”, the KPI will be refreshed, and the newly added KPI will be shown.

Data visualizations

The first Data visualization (Figure 19) shows the average of how much of the planned time is used. This says something about the accuracy of the prediction. If the value in the graph is over 100%, then more time than initially scheduled is used. If less than 100% is used, less time than initially scheduled is used. Usually, it is better to finish sooner than later, but if you talk about predictability, the goal is the have 100% in this graph since then the reality is the same as the scheduled number.

The second graph (Figure 18) shows how many of the tasks within each assembly are finished for over 50%. This is a relevant characteristic to display, since it is hard to say something about the status of predictability of a task when the task has not started yet, or is just at the first out of a hundred hours. So, this graph says something about the reliability of the data, if the amount total is really small, the conclusion is less reliable.

The third graph (Figure 20) shows how much is finished, compared to the planned value. So, this indicates if the planned value was accurate. However, to draw a clear conclusion from this, it is relevant to know how much work is done, therefore it is better to look at the fourth graph. The third graph is most relevant when all activities are finished since it then shows how much more time was used than initially scheduled.

The fourth graph (Figure 21) displays how much has finished compared to the value of the EAC, this value is always under 100% since the EAC is an adjusted number. Therefore it displays how much still needs to be done. The fifth, and final graph (Figure 16) in this section shows the remaining costs to come per assembly, so, how much work still needs to be done. It indicates how far along the project is. A high number in this graph means that a lot still needs to be done, so it is in the early stage of the project. 0, or a small number indicates that the project is (almost) finished.

Milestones

In the last section, the milestones for the upcoming year are displayed. They are in ascending order, so the soonest milestone is seen first. The project name, and project assembly, together with the name of the milestone are shown in the table.

Figure 23: Dashboard zoomed in on top part

Project na	Project asse	Milestone name	Milestone date
Project_6	PCA_6	I-IRM-SW (proto2) en I-LIM-LNA (proto1) gemeten	08-07-2024
Project_2	PCA_2	Critical Item Design Review (CDR)	29-07-2024
Project_2	PCA_2	PDP released (design/develop)	19-08-2024
Project_3	PCA_3	PDR mech - review ksstx housing design, freeze mech positions of feed-throughs and cc	04-09-2024
Project_3	PCA_3	PDR RF - review prelim. RF design (pre-stamp)	09-09-2024
Project_2	PCA_2	Review design specification	02-10-2024
Project_6	PCA_6	Eerste (pilot) I-DOWNCONV gemeten	14-10-2024
Project_1	PCA_10	Boards CDR	14-10-2024
Project_3	PCA_3	Critical Item Design Review (CDR)	23-10-2024
Project_3	PCA_3	PDP released (design/develop)	01-11-2024
Project_3	PCA_3	Review CITS/DBV-plan	01-11-2024
Project_3	PCA_3	Test Readiness Review (TRR)	13-11-2024
Project_3	PCA_3	Technical Qualification Review (TQR)	20-11-2024
Project_1	PCA_10	Mechanical CDR	09-12-2024
Project_2	PCA_2	Review DBV-plan/CITS	16-12-2024
Project_2	PCA_2	HW ready	17-12-2024
Project_2	PCA_2	Test Readiness Review (TRR)	06-01-2025
Project_3	PCA_3	FAI/PER KSSTX	28-01-2025
Project_3	PCA_3	RF HW Ready - KSSTX_PC & all mechanical housings required	29-01-2025
Project_2	PCA_2	Review DBV results/Technical Qualification Review	18-02-2025
Project_3	PCA_3	first set To Work KSSTX	20-02-2025
Project_1	PCA_10	Master CDR	24-03-2025
Project_2	PCA_2	CDR design update	08-04-2025
Project_3	PCA_3	Review DBV results/Technical Qualification Review	09-04-2025
Project_2	PCA_2	PDP released (finalize design)	22-04-2025
Project_2	PCA_2	Maturity Transition Review	29-04-2025
Project_3	PCA_3	CDR redesign	29-04-2025
Project_3	PCA_3	review and release new TPD / PDP	01-05-2025
Project_2	PCA_2	Technical Qualification Review (TQR)	03-06-2025

Figure 24: Dashboard zoomed in on bottom part

6.7 Dashboard design review

To make sure the outcome of this report is as intended, a design review of the dashboard is done. First, we asked the head of department for feedback on the dashboard. He responded that overall the dashboard works as it should, and it meets the design requirements of the RFE department. Since this is not elaborately enough for proper validation, we decided to make a User Experience Questionnaire, the survey questions and results can be found in Appendix I. The survey has been sent to the company supervisor, with the question to forward to engineers who are likely to use the dashboard in the future.

There was one respondent, which makes it hard to give a definitive conclusion, but its answers can be summarized. The dashboard seems sufficient, but there are some improvements possible. In general, the layout can be improved, mainly the layout of the data sheets, including easy navigation back to the dashboard from the data sheets. The dashboard is not that innovative and unique compared to other tools the respondent has used before. The use of slicers in the dashboard is a positive aspect, although it could be added to the milestone table. Moreover, to easily see if the performance is good or bad, it could help to add a red percentage line at 100 percent.

7 Conclusion, limitations and recommendations

In this chapter the conclusion is discussed in subsection 7.1, which is split up into answering the research questions and drawing a conclusion to the main research question. then, in subsection 7.2, the limitations of the research are discussed. Finally, in subsection 7.3, recommendations are given.

7.1 Conclusion

The main research question "How can the predictability of the RFE department of Thales NL be improved?" has been answered by addressing the sub-questions. These sub-questions explore various aspects, such as the current development process, bottlenecks, performance measurements and visualization methods.

1. "What does the current situation of the Radar Front-End engineering department look like, focused on quality, time and costs?"

Currently, Thales NL mainly uses the Waterfall-V model, the incremental model and the Iterative (or evolutive) model, of which the incremental model is the most used by the RFE department. These three models are combined by doing multiple iterations until the developed product meets the quality requirements. These iterations are split up into five phases: orient, design, develop, integrate and verify, and lastly, validate. The Waterfall-V model is mainly focused on verification and validation, combining this with the incremental model means that this verification and validation happens simultaneously to the development phase.

Currently, nine KPIs are used: planning accuracy, design release, PCB production cycle time, PCB production, avg PDP approved to PRR, RFQ PCA → PO PCA, PCA production cycle time, PCA production and avg PCB ready to PRR. These are all measured in days, and they are derived from the development process (Figure 12, Figure 13). Apart from one, RFQ PCA → PO PCA, they are all relevant in terms of predictability. The other KPI is still useful overall, since it is about communication times with a supplier, but that is not relevant to monitor the KPIs on the RFE department. These KPIs can be included in the dashboard, to facilitate an easier monitoring process. These current KPIs are not reliable yet, unfortunately, since they are recently introduced, and with more monthly numbers they will become more reliable.

To get to know more about the current state of the predictability, 10 development plans were analyzed. In case the EAC is higher than the planned budget, the project prediction was not accurate, and the project takes longer. EAC lower than the planned value is also not predictable, but then it finished sooner than expected (hours, not necessarily the date), which is less of a problem than finishing later. To be able to say something about the predictability of a project with certainty, the project needs to be finished. That was not the case for the analyzed projects, so only the tasks that were halfway done or more were included in the analysis. These tasks were used to do some predictability calculations, comparing the EAC with the planned value, the actual value with the planned value, and the actual value with the EAC. Ideally, the outcomes would be 100% for all calculations, but this was rarely the case. However, Apart from the actual value compared with the EAC, which were all lower than 100%, the outcomes were both lower and higher than 100%, so the only conclusion that can be drawn is that most projects were not predictable.

2. "What does the development process on the Radar Front-End Engineering department look like?"

The development process on the RFE department consists of 6 phases: orient, formalize requirements, design, develop, integration and verification and problem integration and verification. During the Orient phase, a development plan is created, in which a personal project planning is made. This includes a WPDD, preliminary requirements description, and design guidelines. The Orient phase is included to define as clearly as possible what needs to be completed and when. This information is recorded in a development plan, which serves as a reference for the development. This development plan is discussed every to weeks during a monitoring session.

During the formalize requirements phase, a more detailed requirement analysis is done, which leads to a DevRR. The design phase includes electronics design, more specialized engineering analyses and a BOM analysis, which includes all necessary components in the design process. It is important to create the BOM early to reduce the dependency on component lead times. During the development phase, several development activities take place, such as performing a design analysis and simulations, defining the hardware architecture, and establishing the EBOM.

In the integration and verification phase, the main focus is on integrating and verifying the developed components, so that it all comes together into one working product. This involves testing the integrated system, to check if all components work together, and meet the specified requirements. During the integration and verification phase, issues and challenges that come up during the process are identified.

3. "What are the bottlenecks in the development process of products in the RFE department?"

The bottleneck analysis addresses several issues causing the lack of predictability. Several methods were used, such as a process flow analysis, root cause analysis, semi-structured interviews with WPMs and someone involved with KPIs and an analysis of development plans.

It is important to take all necessary elements into account in a project and avoid hyperfixation on specific details, without understanding the bigger picture. Another important thing is clear communication among employees, as well as realistic agreements to prevent unrealistic deadlines. To reduce delays, and improve the overall performance, it is also essential to effectively coordinate and integrate the activities within a project.

4. "How can predictability be measured in the RFE department?"

The goal of the RFE department is to improve their predictability in the development process. To measure this, several measurements of predictability are discussed. Predictability can be measured in several ways. The first one is the Say/Do metric, which compares the planned work to the delivered work within a specific time frame. The second one is a system stability analysis, in which the special cause variation is removed, which leads to a focus on common-cause variations, and therefore it measures the stability of the system. Lastly, predictability can be seen as the ability to meet expectations. So, using probability theory and a lead time analysis helps to assess how consistent the predictions are. Another thing that helps to improve predictability, is monitoring specific KPIs.

Before selecting the KPIs, selection criteria need to be set. The KPIs need to be SMART: Specific, Measurable, Achievable, Realistic, and Time-bound. This ensures that the KPIs are clearly defined, quantifiable and relevant. Some new KPIs are defined, but for further clarification, several KPI selection methods are presented. The Key Performance Indicator Assesment Methodology (KAM) focuses on KPI characterization and alignment, it helps to decide on KPIs, weighting criteria, scoring criteria, and identifying KPI pair issues. The AHP is a multi-criteria decision analysis technique, that focuses on breaking down complex decision problems, creating a hierarchical model of criteria and decision factors, and evaluating alternatives. The ANP helps structure complex decision problems by considering relationships and dependencies among criteria and alternatives. Finally, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a decision-making method that evaluates alternatives based on how similar they are to the ideal solution and the worst solution. It helps to rank alternatives based on their overall performance.

Out of the existing KPIs, 8 are relevant in terms of predictability. On top of these, 6 other KPIs are found. Cycle time per phase can be relevant because it indicates how long each phase takes. When enough data is gathered, it can be relevant to check if a pattern can be determined. The planned-to-done ratio shows how much the team has completed at the end of a task. Schedule delivery adherence measures the timeliness and quality of the product, compared with the criteria and baseline schedule. Cost adherence and fault slip-through focus more on the supplier, but since interviewees mentioned some issues with suppliers, it does no harm to monitor the performance of suppliers, and possibly reconsider these suppliers based on their performance.

5. "What is an effective way to visualize the KPIs to give more insight into the performance and predictability?"

Several visualization methods came up during the literature review, such as a dashboard, a balanced scorecard, benchmarking, and a SWOT analysis. A dashboard was judged as the best method because it focuses on operational processes. It monitors real-time performance, and it is easy to draw a conclusion from the visual overview. Moreover, it is possible to do a predictive analysis and determine patterns and trends, when enough data is gathered, which would be of great value in terms of increasing the predictability.

6. "How can the visualization help to become more predictable?"

The dashboard for now only shows a chart of the current KPIs and their goals, but it is recommended to add the calculation of these KPIs and possible new KPIs to the dashboard as well for a more complete overview. Multiple charts are shown on the dashboard, displaying a general overview of planned value, actual value, cost to come, and estimate at completion. Charts of the predictability calculations are also added, so how much planned time is used, how much is finished compared to what is planned, and how much is planned compared to the EAC. Since it is not reliable to conclude the predictability of activities that have not started yet or are still in the starting phase, it is decided to only include tasks that are over 50% complete. A count of these tasks per project assembly is also included in a chart. Finally, the cost to come per assembly is shown, as well as a milestones table that shows the milestones for the upcoming year.

To keep the information in the dashboard up-to-date, a control panel is made. Here, today's date can be refreshed, as well as all charts and tables, and the milestone table. It is also possible to select a specific project or assembly, and KPI. In the current dashboard design, the user is meant to insert new data manually to the datasheet, but in the future, it would be good to add a button on the dashboard where a user could automatically import data.

Overall conclusion

The predictability of the RFE department of Thales NL can be improved by optimizing the development process through different management techniques, such as the Waterfall-V, Incremental, and interactive models that are used now. They can become more predictable by making sure that every task in the process is carefully verified and validated. Implementing clear and measurable KPIs, together with methods such as the Say/Do analysis and system stability analyses, will provide accurate measurements that can help with increasing predictability. It is necessary to address communication issues between steps within the development process and unrealistic deadlines by facilitating better cooperation and setting realistic goals. Furthermore, the reliability of hardware suppliers plays an important role in the reliability and predictability of the RFE department. Finally, the dashboard will help by offering real-time insight into the KPIs, milestones, and current performance.

7.2 Limitations

Although this thesis provides insights into improving the RFE departments' predictability, some limitations must be acknowledged.

Data reliability

During the data analysis of the project plans, it was noticed that a lot of cells were empty. So, for some plans, only a few lines of useful data could be used. This is also visualized by a graph that shows how many lines were useful, and how many lines were not useful. Analyzing more development plans could have provided more data, however, when it is data from a different project, it is still not really relevant. Ideally, all development plans would have been analyzed, but that is not possible within this scope, since there are a lot of development plans. Furthermore, the question is how seriously each development plan is filled out. If the data is there, it still does not mean it is reliable data of good quality. Some people fill in certain numbers because they think that is what their supervisor wants to see.

Moreover, the KPIs that the department currently uses are relatively new, and when the analysis was done, only one month of numbers was available. This makes it difficult to conclude. As more data is collected, the accuracy of the KPIs will improve, which allows for a more reliable conclusion.

Scope

During this research, the focus was on the department itself. However, interviews have indicated that also a lot can be improved outside of the department, think of suppliers. Other external factors also have a lot of impact on predictability, but they cannot always be influenced.

For the analyses, the focus was on projects that were complete, or at least as much as possible. However, while gathering data, it became clear that there is no, or not enough data available on finished projects. Therefore active projects have been used, which are less reliable to conclude from, since a lot can still happen during the final phase of the project.

Generalization

To gather a base of knowledge, literature research has been done. However, the RFE department is a very specific department, and not all literature is directly applicable to this department. It was difficult to find relevant articles, applied to similar companies, so therefore sometimes it is chosen to look into software companies as well, since there are some similarities.

The RFE department at Thales NL specializes in the development of highly complex radar front-end systems, which involve high safety and reliability demands, as well as a deep integration of hardware. The difference between the RFE department of Thales NL and other hardware development companies is the high level of precision that is needed since it is used in critical military and civilian applications. Despite this specificity, there are also similarities in the product development processes, such as supply chain management and quality insurance, which are needed in all hardware developments. These similarities justify the use of literature and methods from general hardware industry practices. Additionally, since the hardware and software are closely integrated in certain contexts, it is also possible to use literature related to iterative development and modular design approaches.

Moreover, within the department, there are also some differences. All projects are new, and different, which makes it hard to be predictable, and draw conclusions. Therefore it might be best to filter the dashboard per project, instead of comparing the projects' performances.

Dashboard validation

Since there was only one extensive answer to the survey, it is difficult to validate the dashboard. When it was pointed out that the approval of the company was not good enough to validate the dashboard, we no longer had access to a company laptop, as well as the office, which made it hard to communicate. Since we did not have any email addresses on our personal laptop apart from the one from our supervisor, we asked him to forward the survey to other engineers who might work with the dashboard in the future. Unfortunately, this was not possible, or it did not happen, so the result was only one response. Ideally, we would have had survey responses from at least 5 people, preferably from several functions to make the validation more reliable.

7.3 Recommendations

To improve the predictability of the RFE department, some recommendations can be done. Implementing these strategies will help to get a more broad overview of the current state of the department's predictability.

Data gathering

To do a broader analysis, and get a better overview of the current state, it is recommended to gather more extensive, usable data. The Excel file can be used to enter all relevant data, and automatically the calculations will be made, and charts can be updated on the dashboard. Having a bigger data sample ensures higher reliability. Moreover, it is recommended to build a historical database to analyze the KPIs. In this way, the reliability and accuracy of the predictability assessments will increase. When more historical data is gathered, patterns and trends in the data can be identified, which can be used for future predictions.

KPI refinements

Based on the literature review, it is advised to use the AHP technique for further refinement of the proposed KPIs. This technique allows for a structured approach to decision-making, and it helps with breaking down the problem into hierarchies, criteria, and alternatives. Subjectivity is removed as much as possible because the AHP provides a framework for assigning weights to criteria, and evaluation is done based on an objective methodology.

ANP is not chosen, because it is broader, so it offers a more complete approach, but that can also cause unnecessary complexity. TOPSIS is more subjective than AHP, and since objectivity and consistency are crucial for the KPI selection on the RFE department, AHP is preferred over TOPSIS. The KAM method is a systematic approach, which is good for consistency, however, it does not offer the same depth and hierarchy as AHP. It would be good to have a more critical look at the new set of KPIs as a whole, together with the existing KPIs, to avoid having to many and unnecessary KPIs.

Development processes
To increase the flexibility and responsiveness to changes, it could be helpful to adapt more of the agile methodology to the current used, waterfall-v model, incremental model, and iterative model. Having more regular meetings may give a better overview of possible issues. Moreover, a lot of time is lost in the flow of one activity to the next. This can mainly be improved by better communicating within steps in the development process, but it could also help to implement an alert on the dashboard, that is activated as soon as an activity is 90% finished. To implement this, it is important to keep the data in the dashboard up-to-date, which can be done in weekly meetings for example.

Realistic deadline
Interviewees brought up that the agreed deadline with the customer is rarely realistic. A project always needs to be cheaper and finished sooner, but it is rarely possible to meet these terms. When a project is delayed, costs will go up. Therefore, it could be valuable to analyze how much extra these projects cost, compared to the deadline that the department thought was realistic. When multiple of these calculations are done, it can be used as an argument during the negotiation, to pressure the customer to set a realistic deadline.

7.4 Future research

Although this thesis presents insight into improving the Radar Front-end Engineering department, there are opportunities for further research on this topic.

Long-term analysis
It could be beneficial to track the implementation and effectiveness of the (recently implemented) current KPIs, together with the newly suggested KPIs in this report. By analyzing a collection of data that is collected over several years, the long-term impact of changes on predictability can be determined.

Comparative Studies
Studies that compare several departments, or even organizations, could provide deeper insights into the most effective strategies for increasing predictability. This comparison could be done by using various KPIs and development models. Studies like these help to generalize findings, and identify universally applicable methods.

Supplier management
Since suppliers have a big impact on the predictability of a process, it could be relevant to explore strategies to better manage the suppliers' performance. New specific KPIs, related to supplier interactions, identifying how supplier dependence affects the predictability of the project as a whole, and evaluating the value of the supplier performance measurements.

Predictive models
To even more improve project outcomes, it might be interesting to look into machine learning algorithms and advanced predictive analytics. These models to predict future results use historical data, current KPIs, and external factors so the accuracy of the predictions is optimized.

7.5 Contribution to theory and practice

This research contributes to theory and practice in several ways, namely on the topics of predictability metrics, management models and dashboard development.

Predictability metrics
Currently, literature related to predictability is not that advanced, especially literature that can be applied to hardware. With this thesis, we tried to bridge this gap. This research provides a theoretical framework that can be used in comparable situations.

Management models
This research offers practical insights into the combination of different development management models like the waterfall-v model, incremental model, and iterative model, to increase the project's predictability.

Dashboard development
The research contributes to practice by developing a dashboard specifically focusing on predictability by showing specific KPIs and project performance related to predictability. This tool can help decision-making since it provides a clear visual overview of the performance. Moreover, the methods are clearly described, and VBA codes are shown, which could be used by other people to build a similar dashboard.

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Appendices

A Appendix A: VBA code calculations of predictability

To calculate the current predictability, we wrote a VBA code which is displayed in Listing 1.

```
Sub check()
    Dim i As Long, w As Worksheet, lastrow As Long
    Dim Plan As Variant, Eac As Variant, Act As Variant, HalfPlan As Variant
    Set ws = ThisWorkbook.Sheets("Ruwe data")
    lastrow = ws.Cells(ws.Rows.Count, 6).End(xlUp).Row

    ws.Range("J2:N100000").ClearContents

    For i = 2 To lastrow
        Plan = ws.Cells(i, 5).Value
        Eac = ws.Cells(i, 8).Value
        Act = ws.Cells(i, 6).Value
        HalfPlan = ws.Cells(i, 9).Value

        If IsEmpty(Plan) Or IsEmpty(Act) Or IsEmpty(Eac) Then
            ws.Cells(i, 10) = "Empty" ' Check if cells of Plan, Actual and EAC are empty
        End If

        If ws.Cells(i, 10) = "" Then ' In case (i,10) is empty (so relevant cells have values)
            If Act >= HalfPlan Then ' Check if actual value is more than or equal to half of the planned time (>=50% complete)
                ws.Cells(i, 11).Value = "Yes" ' If criteria is true, fill in 'Yes' in (i,11)
            End If
        End If

        If ws.Cells(i, 11).Value = "Yes" And Plan <> 0 Then ' If activity >=50% complete and plan is not 0
            ws.Cells(i, 12).Value = Eac / Plan ' Calculate how much of the planned time is used (EAC/Plan)
        Else
            ws.Cells(i, 12).Value = "NA" ' NA in Case activity is <50% complete or plan is empty
        End If

        If ws.Cells(i, 11).Value = "Yes" And Plan <> 0 Then ' If activity >=50% complete and plan is not 0
            ws.Cells(i, 13).Value = Act / Plan ' Calculate how much is finished compared to the planned value
        Else
            ws.Cells(i, 13).Value = "NA" ' NA in Case activity is <50% complete or plan is empty
        End If

        If ws.Cells(i, 11).Value = "Yes" And Plan <> 0 Then ' If activity >=50% complete and plan is not 0
            ws.Cells(i, 14).Value = Act / Eac ' Calculate how much is finished compared to the EAC
        Else
            ws.Cells(i, 14).Value = "NA" ' NA in Case activity is <50% complete or plan is empty
        End If
    Next i
End Sub
```

Listing 1: VBA code for predictability calculations

B Appendix B: VBA code for updating pivot tables

To refresh the pivot tables in each workbook, the VBA scripts below are written. These scripts update specific pivot tables based on their respective worksheets and pivot table names.

```
Sub UpdateGeneralPivotTable()
    Dim ws As Worksheet, pt As PivotTable

    Set ws = ThisWorkbook.Sheets("Pivot Table") 'Define worksheet
    Set pt = ws.PivotTables("General pivot table") 'Set pivot table reference

    pt.RefreshTable 'refresh pivot table
End Sub
```

Listing 2: VBA code to update the General pivot table

```
Sub UpdatePivotTablePercantageTimeUsed()
    Dim ws As Worksheet, pt As PivotTable

    Set ws = ThisWorkbook.Sheets("PercentageOfPlannedTimeUsed") 'Define worksheet
    Set pt = ws.PivotTables("PivotTablePercantageTimeUsed") 'Set pivot table reference

    pt.RefreshTable 'refresh pivot table
End Sub
```

Listing 3: VBA code to update the Percentage Time Used pivot table

```
Sub UpdatePivotTableFinishedVS()
    Dim ws As Worksheet, pt As PivotTable

    Set ws = ThisWorkbook.Sheets("Earned value analysis") 'Define worksheet
    Set pt = ws.PivotTables("PivotTableFinishedVS") 'Set pivot table reference

    pt.RefreshTable 'refresh pivot table
End Sub
```

Listing 4: VBA code to update the Finished VS pivot table

```
Sub UpdatePivotTableCTC()
    Dim ws As Worksheet, pt As PivotTable

    Set ws = ThisWorkbook.Sheets("CostToCome") 'Define worksheet
    Set pt = ws.PivotTables("PivotTableCTC") 'Set pivot table reference

    pt.RefreshTable 'refresh pivot table
End Sub
```

Listing 5: VBA code to update the Cost To Come pivot table

```
Sub UpdatePivotTableCompletionAssembly()
    Dim ws As Worksheet, pt As PivotTable

    Set ws = ThisWorkbook.Sheets("ProjectCompletionStatus") 'Define worksheet
    Set pt = ws.PivotTables("PivotTableCompletionAssembly") 'Set pivot table reference

    pt.RefreshTable 'refresh pivot table
End Sub
```

Listing 6: VBA code to update the Completion Assembly pivot table

```
Sub UpdatePivotTableCompletionProject()
    Dim ws As Worksheet, pt As PivotTable

    Set ws = ThisWorkbook.Sheets("ProjectCompletionStatus") 'Define worksheet
    Set pt = ws.PivotTables("PivotTableCompletionProject") 'Set pivot table reference

    pt.RefreshTable 'refresh pivot table
End Sub
```

Listing 7: VBA code to update the Completion Project pivot table

```
Sub UpdatePivotTableEAC()
    Dim ws As Worksheet, pt As PivotTable

    Set ws = ThisWorkbook.Sheets("Earned value analysis") 'Define worksheet
```

```
    Set pt = ws.PivotTables("PivotTableEAC") 'Set pivot table reference

    pt.RefreshTable 'refresh pivot table
End Sub
```

Listing 8: VBA code to update the EAC pivot table

C Appendix C: VBA code for refreshing all pivot tables and charts

The following VBA scripts refresh all pivot tables and pivot charts. It is linked to a button, so with one click on a button on the dashboard, all pivot tables and charts can be updated.

```
Sub RefreshAllPivotCharts()
    Dim ws As Worksheet
    Dim pt As PivotTable
    Dim pc As ChartObject

    For Each ws In ThisWorkbook.Worksheets 'loop through all worksheets
        For Each pt In ws.PivotTables 'refresh all pivot tables in each worksheet
            pt.RefreshTable
        Next pt
        For Each pc In ws.ChartObjects 'loop through all pivot charts
            On Error Resume Next
            If Not pc.Chart.PivotLayout Is Nothing Then
                pc.Chart.PivotLayout.PivotTable.RefreshTable 'refresh charts if they
    are found
            End If
            On Error GoTo 0
        Next pc
    Next ws

    MsgBox "All Pivot Tables and Pivot Charts have been refreshed", vbInformation '
    message that charts and tables have been refreshed

End Sub
```

Listing 9: VBA code to refresh all pivot tables and pivot charts

D Appendix D: VBA code for navigating to a sheet

The vba codes below are written to navigate to a specific sheet. There is a button for each sheet on the dashboard, which makes it easy to navigate through the excel file.

```
Sub GoToPivotTable()
    Sheets("Pivot Table").Activate 'go to sheet
End Sub
```

Listing 10: VBA code to navigate to the Pivot Table sheet

```
Sub GoToProjectCompletionStatus()
    Sheets("ProjectCompletionStatus").Activate 'go to sheet
End Sub
```

Listing 11: VBA code to navigate to the Project Completion Status sheet

```
Sub GoToEarnedValueAnalysis()
    Sheets("Earned value analysis").Activate 'go to sheet
End Sub
```

Listing 12: VBA code to navigate to the Earned Value Analysis sheet

```
Sub GoToCostToCome()
    Sheets("CostToCome").Activate 'go to sheet
End Sub
```

Listing 13: VBA code to navigate to the Cost To Come sheet

```
Sub GoToPercentageOfPlannedTimeUsed()
    Sheets("PercentageOfPlannedTimeUsed").Activate 'go to sheet
End Sub
```

Listing 14: VBA code to navigate to the Percentage of Planned Time Used sheet

```
Sub GoToGeneralOverview()
    Sheets("General overview").Activate 'go to sheet
End Sub
```

Listing 15: VBA code to navigate to the General Overview sheet

```
Sub GoToKPIs()
    Sheets("KPIs").Activate 'go to sheet
End Sub
```

Listing 16: VBA code to navigate to the KPIs sheet

```
Sub GoToUsefulData()
    Sheets("Useful data").Activate 'go to sheet
End Sub
```

Listing 17: VBA code to navigate to the Useful Data sheet

```
Sub GoToMilestones()
    Sheets("Milestones").Activate 'go to sheet
End Sub
```

Listing 18: VBA code to navigate to the Milestones sheet

```
Sub GoToRawData()
    Sheets("Raw data").Activate 'go to sheet
End Sub
```

Listing 19: VBA code to navigate to the Raw Data sheet

```
Sub GoToUnusableData()
    Sheets("Unusable data").Activate 'go to sheet
End Sub
```

Listing 20: VBA code to navigate to the Unusable Data sheet

E Appendix E: VBA code for displaying the milestones on the dashboard

The VBA script below displays the milestones for the upcoming year on the dashboard.

```
Sub DisplayUpcomingMilestones()
    Dim wsMilestones As Worksheet
    Dim wsDashboard As Worksheet
    Dim milestoneRange As Range
    Dim filterDate As Date
    Dim lastRow As Long
    Dim copyRange As Range

    ' Set the worksheets
    Set wsMilestones = ThisWorkbook.Sheets("Milestones")
    Set wsDashboard = ThisWorkbook.Sheets("Dashboard")

    filterDate = Date + 365 ' Set the filter date to one year from today

    lastRow = wsMilestones.Cells(wsMilestones.Rows.Count, "D").End(xlUp).Row  ' Find
    the last row in the Milestones sheet (skip headers)

    Set milestoneRange = wsMilestones.Range("A1:D" & lastRow) ' Set the range to
    filter

    milestoneRange.AutoFilter Field:=4, Criteria1:=">=" & Date, Operator:=xlAnd,
    Criteria2:="<=" & filterDate ' Apply filter to show only milestones within the next
     year
```

```

    wsDashboard.Range("A95:G" & wsDashboard.Cells(wsDashboard.Rows.Count, "G").End(xlUp).Row).ClearContents ' Clear the previous data in the Dashboard sheet

    ' Copy the filtered data to the Dashboard sheet starting from B95 (bottom left, after dashboard charts)
    On Error Resume Next ' In case no data matches the filter criteria
    Set copyRange = wsMilestones.Range("A2:D" & lastRow).SpecialCells(xlCellTypeVisible)
    On Error GoTo 0

    ' Check if there is any visible data to copy
    If Not copyRange Is Nothing Then
        wsMilestones.Range("A1:D1").Copy wsDashboard.Range("B96") ' Copy the headers from the Milestones sheet
        copyRange.Copy wsDashboard.Range("B97") ' Copy the filtered data from the Milestones sheet to Dashboard

        With wsDashboard.Sort ' Apply sorting by milestone date in ascending order
            .SortFields.Clear
            .SortFields.Add Key:=wsDashboard.Range("E97:E" & wsDashboard.Cells(wsDashboard.Rows.Count, "B").End(xlUp).Row), _
                SortOn:=xlSortOnValues, Order:=xlAscending
            .SetRange wsDashboard.Range("B96:E" & wsDashboard.Cells(wsDashboard.Rows.Count, "B").End(xlUp).Row)
            .Header = xlYes
            .Apply
        End With
    Else
        wsDashboard.Range("B97").Value = "No upcoming milestones within the next year." ' If no milestones within the next year, leave a message in the dashboard
    End If

    wsMilestones.AutoFilterMode = False  ' Turn off autofilter

    wsDashboard.Columns("B:E").AutoFit  ' Adjust the column width in the Dashboard sheet for better display
End Sub
```

Listing 21: VBA code to display upcoming milestones on the dashboard

F Appendix F: VBA code for creating a clear layout

SetDashboardAppearance is written to make a blue background, and a white font.

```
Sub SetDashboardAppearance()
    Dim wsDashboard As Worksheet

    Set wsDashboard = ThisWorkbook.Sheets("Dashboard") ' Set the worksheet

    wsDashboard.Cells.Interior.Color = RGB(35, 43, 115)  ' Set the background color of the entire Dashboard sheet to RGB(35,43,115)

    wsDashboard.Cells.Font.Color = RGB(255, 255, 255) ' Set the font color of the entire Dashboard sheet to white

End Sub
```

Listing 22: VBA code to set dashboard appearance

DisplayTodaysDate displays the date of today. It is linked to a button in the control panel.

```
Sub DisplayTodaysDate()

    With ThisWorkbook.Sheets("Dashboard").Range("B9")  'display "Today's date:" in cell B9
        .Value = "Today's date:"
        .Font.Bold = True
    End With

    With ThisWorkbook.Sheets("Dashboard").Range("C9")  'display todays date
```

```
        .Value = Date
        .Font.Bold = True
    End With
End Sub
```

Listing 23: VBA code to display today's date on the dashboard

G Appendix G: Systematic literature review

Research question

"What is an effective way to visualize the KPIs to give more insight into the performance and predictability?"

Inclusion and exclusion criteria

Table 6 shows the inclusion and exclusion criteria for the systematic literature review, together with a justification for each criterion.

Table 6: Inclusion and exclusion criteria

Inclusion criteria	Justification
Articles published in the last 10 years (after 2014)	Visualization techniques advance rapidly, new tools and software are used. It is not useful to look at articles which are about software that is not used anymore nowadays.
Limit subject area to Business, management and accounting	Too many irrelevant articles show up if this is not limited to the relevant area
Exclusion criteria	**Justification**
Full text is not accessible	It is not possible to draw a well-informed conclusion if the full article and method cannot be accessed.
Articles in languages other than English and Dutch	Articles in other languages cannot be understood.

Academic databases

The academic databases used are Scopus and Web of Science. These are both mentioned as the most important databases for Industrial Engineering and Management by the UT. Scopus is a large database that covers social sciences, science and technology among others (UniversityLibrary, 2024). To do a broader literature review, it is good to also use another database. Web of Science is also to check for other relevant articles, a large database containing articles from high-impact research journals and conferences.

Search terms

Table 7 shows the search terms, split up in broader and narrower terms per key concept.

Number of search results

Table 8 shows the number of hits per action. First the references will be screened on title, to find out if the search query makes sense. The total hits, and the relevant number of hits are indicated per search query in the table below. After this, the duplicates will be removed from the relevant articles (see table 6 for the duplicates). When duplicates are removed, the abstract will be read thoroughly, and irrelevant items will be removed, 17 references are left. Finally, the full text of the remaining articles will be accessed for eligibility. The remaining articles after these selections can be used for answering the research question. While answering the research question, it is decided not to use 3 articles, because they do not add much value to the other articles. However, one of the articles used a lot of sources, and these sources had to be copied to avoid plagiarism, so another 8 sources are added to the final list of sources.

Table 7: Search terms

Key concepts	Related terms	Broader terms	Narrower terms
1. Visualization	Dashboard, graphical, visual model, control board, interface, monitor, analysis, charts and graphs, scorecard, insight, predictability, model	Dashboard, interface, visual model, control board, charts and graphs, scorecard	Graphical, monitor, analysis, insight, predictability, model
2. KPIs	Key performance indicator, performance measurement, metrics, key success indicators, performance indicators, business metrics, targets, benchmarking	Key performance indicator, key success indicators, benchmarking	Performance measurement, metrics, performance indicators, business metrics, targets
3. Lead times	Periods, time, phase, stage, timeline, duration, cycle time, processing time, throughput time	Cycle time, processing time, throughput time	Periods, time, phase, stage, timeline, duration
4. Costs	Value, price, expense, money, budget, cost overrun	Budget, expense, cost overrun	Value, price, money

Table 8: Number of hits

Number of articles	Total number
Total number of hits	329
Selecting relevance based on title	-280
Removed duplicates	-15
Removed based on abstract	-17
Removed based on full-text assessment (content)	-9
Removed based on full-text assessment (did not meet the inclusion/exclusion criteria)	-2
References added because they are used in an article found in the SLR	+8
Articles that were first selected, but are not of additional value after reading the other articles	-3
Total used for the integration of theory	11

Search log

Table 9 shows the search log of the systematic literature review. Date, source, search string, total number of hits and remarks are specified. Finally, duplicates are removed.

Table 9: Search log

Date	Source	Search string	Total hits	Remarks
4/8/2024	Scopus	(visual* OR dashboard OR interface OR ”visual model” OR ”control board” OR ”charts and graphs” OR scorecard) AND (KPI* OR ”key performance indicator” OR ”key success indicator”) AND ”lead time” AND (budget OR cost* OR expense OR ”cost overrun”) Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	0	Too specific terms combined, may need to try to use more terms or less specific terms
4/8/2024	Scopus	(visual* OR dashboard) AND (KPI OR “key performance indicator”) AND (budget OR cost*) AND “lead time” Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	0	Too specific, need to combine more terms
4/8/2024	Scopus	dashboard AND KPI Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	1	1 relevant
4/8/2024	Scopus	(dashboard OR visual*) AND (KPI OR ”key performance indicator”) Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	31	22 relevant

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Table 9 – continued from previous page

Date	Source	Search string	Total hits	Remarks
4/8/2024	Scopus	(dashboard OR visual*) AND (KPI OR "key performance indicator") AND (buget OR cost*) Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	5	3 relevant
4/8/2024	Scopus	(dashboard OR visual*) AND (KPI OR "key performance indicator") AND time Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	7	5 relevant
5/8/2024	Scopus	(visual* OR dashboard OR interface OR "visual model" OR "control board" OR "charts and graphs" OR scorecard) AND ("Key performance indicator" OR "key success indicators" OR benchmark* OR KPI) Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	208	Too broad to scan through everything
5/8/2024	Scopus	(visual* OR dashboard OR interface OR "visual model" OR "control board" OR "charts and graphs" OR scorecard) AND ("Key performance indicator" OR "key success indicators" OR benchmark* OR KPI) AND ("lead time" OR "lead times" OR "cycle time" OR "processing time" OR "throughput time" OR "delivery time" OR " reorder time") Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	2	2 relevant
5/8/2024	Scopus	(visual* OR dashboard OR interface OR "visual model" OR "control board" OR "charts and graphs" OR scorecard) AND ("Key performance indicator" OR "key success indicators" OR benchmark* OR KPI) AND (cost* OR budget OR Expen* OR "cost overrun") Limited to Business, Management and accounting, English, Dutch, all open access, 2014-now	30	12 relevant
5/8/2024	Web of Science	TI = ((visual* OR dashboard OR interface OR "visual model" OR "control board" OR "charts and graphs" OR scorecard) AND ("Key performance indicator" OR "key success indicators" OR benchmark* OR KPI) AND (cost* OR budget OR Expen* OR "cost overrun") OR AB= ((visual* OR dashboard OR interface OR "visual model" OR "control board" OR "charts and graphs" OR scorecard) AND ("Key performance indicator" OR "key success indicators" OR benchmark* OR KPI) AND (cost* OR budget OR Expen* OR "cost overrun") OR AK= ((visual* OR dashboard OR interface OR "visual model" OR "control board" OR "charts and graphs" OR scorecard) AND ("Key performance indicator" OR "key success indicators" OR benchmark* OR KPI) AND (cost* OR budget OR Expen* OR "cost overrun") Limited to 2014-04-09 – 2024-04-09, English, Open access, Research area: Operations Research Management Science or Automation control Systems	44	3 relevant

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Table 9 – continued from previous page

Date	Source	Search string	Total hits	Remarks
5/8/2024	Web of Science	TI = ((visual* OR dashboard OR interface OR “visual model” OR “control board” OR “charts and graphs” OR scorecard) AND (“Key performance indicator” OR “key success indicators” OR benchmark* OR KPI) AND (cost* OR budget OR Expen* OR “cost overrun”) AND (“lead time” OR “cycle time” OR “processing time” OR “throughput time”)) OR AB= ((visual* OR dashboard OR interface OR “visual model” OR “control board” OR “charts and graphs” OR scorecard) AND (“Key performance indicator” OR “key success indicators” OR benchmark* OR KPI) AND (cost* OR budget OR Expen* OR “cost overrun”) AND (“lead time” OR “cycle time” OR “processing time” OR “throughput time”)) OR AK= ((visual* OR dashboard OR interface OR “visual model” OR “control board” OR “charts and graphs” OR scorecard) AND (“Key performance indicator” OR “key success indicators” OR benchmark* OR KPI) AND (cost* OR budget OR Expen* OR “cost overrun”) AND (“lead time” OR “cycle time” OR “processing time” OR “throughput time”)) Limited to 2014-04-09 – 2024-04-09, English, Open access, Research area: Operations Research Management Science or Automation control Systems	1	1 relevant
Total			329	49
Total after duplicates removal				34

Duplicate articles

Table 10 indicated the articles that were found multiple times. A total of 15 references are removed because there were dupicates.

Table 10: Duplicate articles

Article	Amount per reference	Amount to remove
Using of KPIs and dashboard in the analysis of Carrefour company's performance management	5	-4
Towards CSR and the sustainable enterprise economy in the Asia Pacific region	2	-1
Measuring performance in hospitals: the development of an operational dashboard to coordinate and optimize patient, material and information flows	2	-1
Design and development of a performance evaluation system for the aircraft maintenance industry	2	-1
Performance management methods: A case study from international industrial companies	3	-2
Impact on network performance of probe vehicle data usage: an experimental design for simulation assessment	2	-1
Digital customer experience engineering: strategies for creating effective digital experiences	4	-3
Design, implementation and assessment of a more sustainable model to manage plastic waste at sports events	2	-1
Framework for continuous improvement of production process and product throughput	2	-1
Total duplicates	**24**	**-15**

Articles added through other articles

While writing the integration of the theory, one article mentioned a lot of useful aspects, which were cited from other sources. Therefore, in some cases, these sources were cited instead of the initial articles. These sources are mentioned in Table 11.

Table 11: Articles added through other articles

Article from SLR	Used citation from article
Warehouse management problem and a KPI approach: a case study	• (Vollmann et al., 2005) • (Gunasekaran and Kobu, 2007) • (Neely, 2007) • (Lohman et al., 2004) • (Kucukaltan et al., 2016) • (Sangwan, 2017) • (Rafele, 2004) • (Drucker, 2007)

Conceptual matrix

For all remaining articles is checked what useful information is in there. It is concluded whether an article is useful, and additional comments are made. This can be found in Table 12.

Table 12: Full text review

Article	What is in there	Useful or not	Comments
Warehouse management problem and a KPI approach: a case study (Marziali et al., 2021)	• They provide a clear and quantifiable measure of performance. • They help in monitoring progress and identifying areas for improvement. • They enable organizations to align their operations with strategic goals. • They facilitate better decision-making based on data-driven insights.	Yes	Focused mainly on KPIs, which are answered in a different research question. Control tools are also built, however, the method for building a tool is not that extensively discussed.
Using of KPIs and dashboard in the analysis of Carrefour company's performance management (Nica et al., 2021)	• Knowledge based organization • Hierarchy of knowledge • Big data • Methods for measuring performance of a company • Customer relationship management tool • Dashboard (features and elaboration) • Balanced scorecard • Benchmarking • KPIs (SMART) • Case study	Yes	Focused mainly on KPIs, which are answered in a different research question. Control tools are also built, however, the method for building a tool is not that extensively discussed.
Towards CSR and the sustainable enterprise economy in the Asia Pacific region	-	No	Not possible to open (log in with UT account on Emerald not possible)
SMART-QUAL: a dashboard for quality measurement in higher education institutions	-	No	Account must be made, and access must be requested so not open access
Supply Chain Digitalization Framework for Service/Product Satisfaction (Murumaa et al., 2021)	• Supply chain reliability metrics (SCOR) • Bayesian belief network (BBN)	No	Specific case, not a lot of explanation so information is hard to apply
Performance management methods: A case study from international industrial companies (Kuzmanovic et al., 2019)	• Theoretical background of performance management (KPIs) • input-process-output-outcome model • Connectance model • Statistics	No	Some parts might be useful; however it doesn't add much value to the other articles that are more relevant. The focus is on statistics, and KPIs.
Meta-choices in ranking knowledge-based organizations (Daraio et al., 2022)	• Meta choices • Intellectual capital • University rankings (statistics)	No	It has a different point of view than the previously assessed articles, which makes it interesting. However, most information is not useful to answer the research question.

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Table 12 – continued from previous page

Article	What is in there	Useful or not	Comments
Impact on Network Performance of Probe Vehicle Data Usage: An Experimental Design for Simulation Assessment (Montero et al., 2018)	• Focused on a vehicle network simulation	No	Not relevant for answering the research question, since they are doing a simulation, and they don't really make a clear visualization tool that can be used for the RFE department research.
Genetic algorithm optimisation of a class of inventory control systems (Disney et al., 2000)	• Inventory policy • Scheduling • Algorithm	No	Focused on algorithm optimization, not on creating a visualization
From Wireframe to Dashboard – Creating Transparency in Supply Chain Networks (Orenstein, 2023)	• Data visualization • Supply chain analysis • Financial and structural dashboards	No	Focus is on mapping the supply chain network, a clear method for how to make a financial and structural dashboard is not mentioned
Framework for Continuous Improvement of Production Processes and Product Throughput (Jevgeni et al., 2015)	• KPIs • Failure classifier • Failure mode and effect analysis • Six sigma • Lead time in manufacturing • Theory of constraints • Framework for continuous improvements	Yes, but not used, not of added value after reading the other articles)	The article mentions a lot of models/methods which can be useful. Moreover, a framework for continuous improvements is shown, which can be useful.
Factors influencing control charts usage of operational measures (Ericson Öberg et al., 2017)	• Control charts • KPIs • Factors of a perceived successfull implementation of control charts of KPIs • Different control chart models are mentioned	Yes, but not used (not of added value after reading the other articles)	Different methods for implementing a control chart are mentioned, as well as KPIs and how to successfully implement a control chart
Enterprise modeling for business intelligence (Barone et al., 2010)	• Different business intelligence models are mentioned	Yes	DThis source is more focused on models than the previously mentioned sources
Design and development of a performance evaluation system for the aircraft maintenance industry (Ng et al., 2016)	• KPIs monitoring a BI system	Yes, but not used (not of added vale after reading the other articles)	Visualizes KPIs in a dashboard, but the method is not clearly described. However, it can still be useful to answer the research question
Balanced scorecard in Indian companies (Anand et al., 2005)	• Balanced scorecard	No	The article is only about balanced scorecards, which is not that useful right now. However, if a balanced scorecard will be used, this article can be relevant, but for now this topic is already explained in other articles.
A Systematic Review of Compliance Measurement Based on Goals and Indicators (Shamsaei et al., 2011)	• Focused on compliance measurement (laws and regulations)	No	Not relevant to answer the research question

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Table 12 – continued from previous page

Article	What is in there	Useful or not	Comments
A System Supporting the Analysis of Motorway Traffic Accidents (Anghinolfi et al., 2015)	• Databases • Road segmentation analysis • Linear geographical visualizer	No	Too much focus on road analysis which makes that it is not useful to answer the research question
Total included	**6**	**Total excluded**	**11**

H Appendix H: Questions for the interview

The interviews were prepared and held in Dutch, so to include the questions in the report, they are translated into English.

1. **How do you perceive predictability?**
    - How important is predictability to you, and why?
2. **What is the basis for a planning?**
    - How do you determine in advance how long something will take?
    - Do you use certain methods, or is it purely based on experience? And what type of methods would you then use?
    - How are the risks identified during the project planning process?
        - Are there risks that can be prevented?
            * Could you provide an example?
    - How do you prioritize tasks?
3. **What is the biggest challenge in being predictable?**
4. **How much does reality deviate from the initial plan?**
    - When do you find out it deviates, and how is the plan adjusted?
    - How do you deal with unforeseen circumstances during a project?
        - Could you provide an example?
5. **What are the most common causes of delays within a project?**
    - Are the causes different each time, or does the same issue occur more often, and possibly take longer to fix?
    - What are the bottlenecks in the development process?
6. **What kind of overview/data do you think would help to become more predictable**
    - How reliable are the current predictions?
7. **Which KPIs are relevant for measuring the predictability?**
    - How are these KPIs relevant and reliable?
    - How is the accuracy of predictions measured?

I Appendix I: Survey questions

The following questions are included in a survey to get feedback on the dashboard. The survey is in Dutch to avoid misunderstanding, since all respondents are dutch. Apart from the last question, all questions are Likert scale questions, from 1 to 7, with 1 completely disagree, and 7 completely agree. The last question is an open question. The collected answer is also included.

Attractiveness

1. The visual design of the dashboard is attractive. (4)
2. The overall layout of information is well organized. (4)

Usability

1. Navigating through different sections of the dashboard is easy. (3)
2. It is easy to find the specific information I am looking for. (4)

Engagement

1. Using the dashboard motivates and encourages me to explore more. (4)
2. The dashboard provides insights that are stimulating and interesting. (5)

Efficiency

1. I can quickly understand the current KPI values from the dashboard. (4)
2. The dashboard helps me efficiently track planned versus actual progress. (4)

Uniqueness

1. The dashboard feels innovative and unique compared to other tools I have used. (3)

Reliability

1. I trust the data and calculations presented in the dashboard. (5)

Overall experience

1. Overall, I am satisfied with the dashboard. (4)
2. How likely are you to recommend improvements or additional features for the dashboard? (6)
3. Please share any specific strengths or areas for improvement you have noticed in the dashboard. (Open question)

   Strengths: the ability to use slicers to select specific projects or PCAs

   Areas for improvement: Also add slicers for the milestone table, improve the layout of the other sheets and make it possible to easily navigate back to the dashboard, it is not that easy to see at a glance if the performance is good or bad, it might help to add a red percentage line at 100 percent.

J Appendix J: Statement on the use of AI

While writing this thesis, the author used ChatGPT to come up with more related search terms for the systematic literature review. Moreover ChatGPT has been used to fix table formatting issues in Latex, as well as changing VBA code to Latex formatted VBA code (list format), and fixing errors when writing subs in VBA. Mendeley has been used as reference manager to easily store and manage all references used, but the .bib file has been changed manually to make it work in Latex correctly.