Using a Lean Method to Improve a Railway Infrastructure Quality Procedure

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August 2025

ProRail

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This report was written as a graduation assignment as part of the bachelor Industrial Engineering and Management.

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Preface

Dear reader,

I am proud to present my thesis: Using a Lean Method to Improve a Railway Infrastructure Quality Procedure. With this thesis my Bachelor's degree in Industrial Engineering and Management is finalized. Writing this thesis has been a challenging, but very valuable experience and I am very grateful for everyone who has supported me during this process.

I would like to thank my supervisor at ProRail for all the help, constructive feedback and opportunities I have been given. Presenting my research to the entire department and getting the opportunity to talk to employees about all different functions ProRail has to offer were great highlights. I am very grateful for the great atmosphere in which I was able to execute my research. The genuine interest and openness of all the employees have inspired me and created a very nice environment for the execution of my research.

I would also like to thank my first university supervisor Dr.ir. M. Koot, and my second supervisor Dr. M. C. van der Heijden for their valuable feedback and support and helping me find a direction when I felt stuck.

A big thanks to my friends and family for supporting me during this process and keeping me motivated.

Lastly, thank you to the reader for taking the time to read this thesis.

Sincerely,

Anne Hoogeveen
August 2025

Management Summary

This thesis focuses on the improvement of a railway infrastructure quality procedure used at ProRail. ProRail manages all railway infrastructure in the Netherlands and while doing so they use multiple procedures. One of those procedures is the RAMSHE LCM procedure, which ensures the quality of new railway infrastructure by analyzing the Reliability, Availability, Maintenance, Safety, Health, Environment and Life Cycle Costs during the projects. The procedure is a fourteen step plan explaining how specific RAMSHE LCM analyses should be performed within an infrastructure project and can be seen as a process in which information is gathered, processed and stored.

The initial problem as experienced by ProRail is that the use rate of the RAMSHE LCM procedure is too low. An initial survey performed among multiple Technical Project Leaders showed a use rate of 29%. This is a problem since the execution of the procedure helps with better decision making in large railway infrastructure projects leading to lower costs and better life cycle management. An initial problem analysis was performed by having conversations with employees who are specialized in the procedure and performing a short survey among one of the main user groups of the procedure. The problem analysis confirmed the low use rate and gave insight into the possible core problems. The fact that the purpose and value of the procedure is not clear has been selected as the core problem of this thesis.

The DMAIC method has been selected as a way of structuring and executing the research. This Lean Six Sigma approach is often used for process improvement and allows us to measure the performance of the procedure and suggest improvements. DMAIC stands for define, measure, analyze, implement and control.

In the **Define** phase, the current procedure is analyzed, a stakeholder analysis is performed and an overview of the desired outcomes and characteristics is created by performing semi-structured interviews with stakeholders. The desired characteristics are translated into 'Critical to Quality' or CTQs. Multiple Lean Six Sigma researches use CTQs during the define phase as a way to create an overview of what qualities a process should have in the eyes of the customer. In the case of this research the customers are the employees since they are the ones that need to use the procedure. The CTQs show what qualities the procedure should have according to the main stakeholders of the procedure. The CTQs have been ranked on how often they have been mentioned during the interviews. We found that the most mentioned CTQ was the fact that the employees should have sufficient knowledge about the procedure.

In the **Measure** phase, literature on lean information management is used to identify the waste within the procedure. The earlier identified CTQs are connected to the different types of information waste to create an overview of what waste could possibly be present in the procedure. A survey has been created to measure the performance of the procedure by asking respondents about their level of agreement about the performance of the CTQs. A 5-point Likert scale was used for this measurement. Further questions about the functions of the respondents, their level of knowledge about the procedure and how important they thought the CTQs were, were also asked during the survey.
A total of 109 responses were gathered. We found that only 40.6% of the respondents that should work with the procedure actually know about its existence. The use rate is even lower with 30%. Approximately 70% of the respondents that know about the procedure indicate to understand the value of the procedure. This seems high, but when taking into account that only 40.6% of the respondents know the procedure, the value is not clear to everyone. Furthermore, nine out of the fifteen CTQs were experienced to be under performing.

In the **Analyze** phase, we select 9 of the 15 CTQs for further analysis. These CTQs on average scored insufficient on performance, but higher than a 7 on importance. For these nine CTQs we performed a 5 Whys analysis in order to identify the root causes leading to the bad performance of the CTQs. Nine root causes were identified during the root cause analysis.

In the **Improve and Control** phase, improvements are suggested to tackle all the root causes and an impact-effort matrix is used to create the implementation advice. Furthermore, the impact of the proposed improvements on the waste in the procedure is analyzed and we find that all the seven types of waste are tackled by the improvements. The waste types overproduction and defects will be most impacted by the proposed improvements. The implementation advice is visualized with a flowchart and

suggestions are made to ensure sustainable improvement.

This thesis proposes to increase the use rate of the procedure by implementing seven improvements. The order in which the improvements should be implemented is shown in the flowchart in Figure 1.

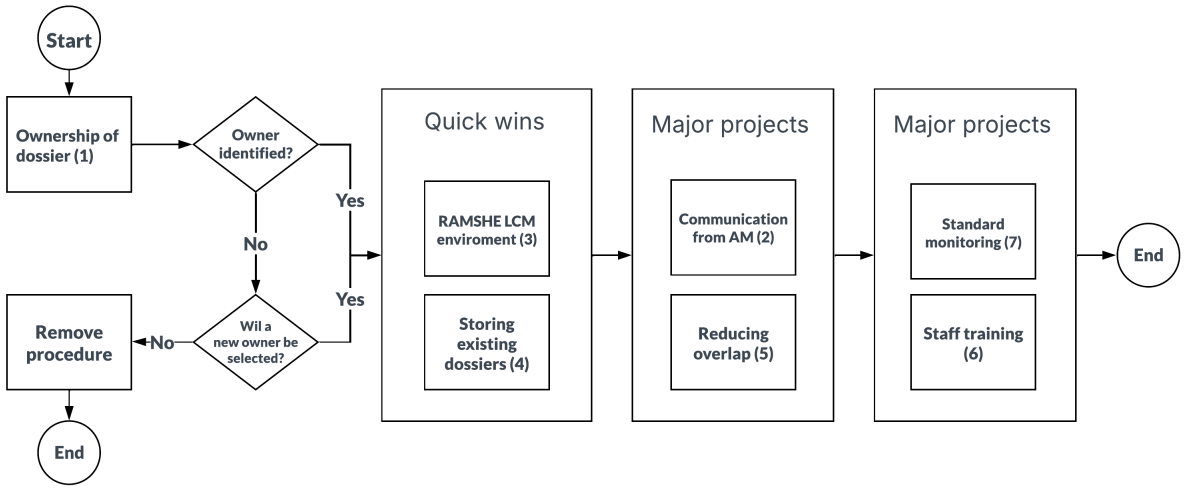


Figure 1: Flowchart for improvement implementation

The first improvement is about the ownership of the definitive RAMSHE dossier. This is the main output of the RAMSHE LCM procedure, but it is currently not clear how it is exactly used and who is responsible for maintaining it. The first step should therefore be to clarify who is responsible for this. If it turns out that there is currently no one actually using the dossiers, we recommend to seriously reflect on whether there should be and possibly incorporate the procedure in other existing procedures. The next improvement should be to create an online RAMSHE LCM environment in which the progress of the procedure is tracked and all documentation can be found. Then, all finalized dossiers should be stored in an accessible place so that they can be used as input for new projects. The fifth improvement is to improve the communication from Asset Management so that it is more clear what they exactly use from the output of the procedure. Then, the overlap between the RAMSHE LCM and other procedures should be reduced. Once these improvements have been executed, the last two improvements can be implemented, namely ensuring that there will be standard monitoring of the execution of the procedure and instating a mandatory staff training on the execution of RAMSHE LCM.

The combination of these improvements tackle the factors leading to a low use rate as identified in the problem identification of this thesis. These factors are: a low ease of use, high perceived effort, the procedure is unknown to many employees and the value of the activities is not clear. Since all factors are addressed we can conclude that the use rate will go up. The proper monitoring of the execution of the procedure will ensure that the use rate stays up.

To ensure sustainable improvement, PDCA (Plan Do Check Act) cycles should be used. Furthermore, the IMPROVE program within ProRail, which supports successful implementation of change and improvements can help with implementing the proposed improvements.

Further research into the execution of the measure phase of the DMAIC cycle within complex non-manufacturing processes or procedures would be valuable.
Once the use rate of the procedure is up, we advise ProRail to look into how the RAM performance of the new infrastructure can best be monitored. When the procedure is consistently used, many opportunities are opened up for gathering more relevant data and making better decisions using that data.

Contents

List of abbreviations

Abbreviation	Description
AO&I	Asset Development & Information
CM	Capacity Management
CRS	Customer Requirement Specification
CTQ	Critical to Quality
DO	Daily Operation
LCM	Life Cycle Management
LSS	Lean Six Sigma
Planco	Plan Coordinator
PLON	Plan Developer
Proj.mgr	Project Manager
RAM	Reliability, Availability, Maintainability
RASCI	Responsible, Accountable, Supports, Consults, Informed
RASCI-table	Describes type of responsibility of employee at certain activity
SHE	Safety, Health, Environment
SRS	System Requirement Specification
TPL	Technical Project Leader
V&V	Verification & Validation

Table 1: List of Abbreviations and Descriptions

Chapter 1: Introduction

This chapter will give an introduction of the background of the research in Section 1.1. The observed problem and its context is described in Section 1.2. Lastly, the problem solving approach is introduced in Section 1.3. The problem solving approach will serve as a guideline for the content of this thesis.

1.1 Background

1.1.1 ProRail

The research is performed at ProRail. ProRail is responsible for all railway infrastructure in The Netherlands. This means that they construct, maintain, and manage the Dutch railway. The mission of ProRail is the following: *"We unite people, cities and companies through railway. Now and in the future. We enable pleasant travel and sustainable transport and ensure that it is safe on and around the railway"*(ProRail B.V., 2025).

Yearly, more than 1.2 billion euros are spent on different infrastructure projects. These projects range from small to very big, examples being renovating a single railway crossing and the current renovation of Amsterdam Central Station to make sure that the station can handle the expected increase in travelers.

ProRail is a very large organization that exists out of 14 clusters, which are, for example, Procurement, Capacity Management, ICT and Asset Management (AM). AM aims to maximize the long-term value of the rail infrastructure. There are four subdepartments within AM: Asset Development & Information, Daily Operation, Quality & Safety and Techniek. The department Techniek can be seen as the knowledge cluster in the field of rail technical knowledge within ProRail. AM Techniek itself exists out of 8 subdepartments. The research environment of this thesis will for the most part be the subdepartment RailTechniek. Figure 2 shows the location of RailTechniek within the AM Techniek department

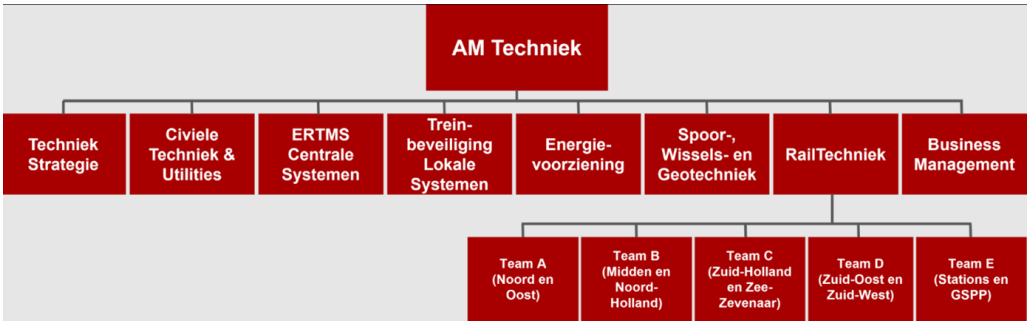


Figure 2: Organogram AM Techniek

1.1.2 AM RailTechniek

AM RailTechniek consists of approximately 150 employees. The department ensures the quality of the scope of infrastructure projects, which means that the requirements of all stakeholders are thoughtfully translated into a suitable solution. Their process runs from customer request to tender file (aanbestedingsdossier). The customer request could for example come from municipalities, provinces or port companies. The tender file is transferred to Construction Management, which falls under the department Projecten. They are then responsible for the contractmanagement with the contractor. Figure 3 visualizes the explained role AM RailTechniek plays within ProRail and their connection with other departments. It also visualizes the goal of the department:

"We guarantee craftsmanship in directing an integral solution for the rail system. We do this in connection with each other, our environment and stakeholders."

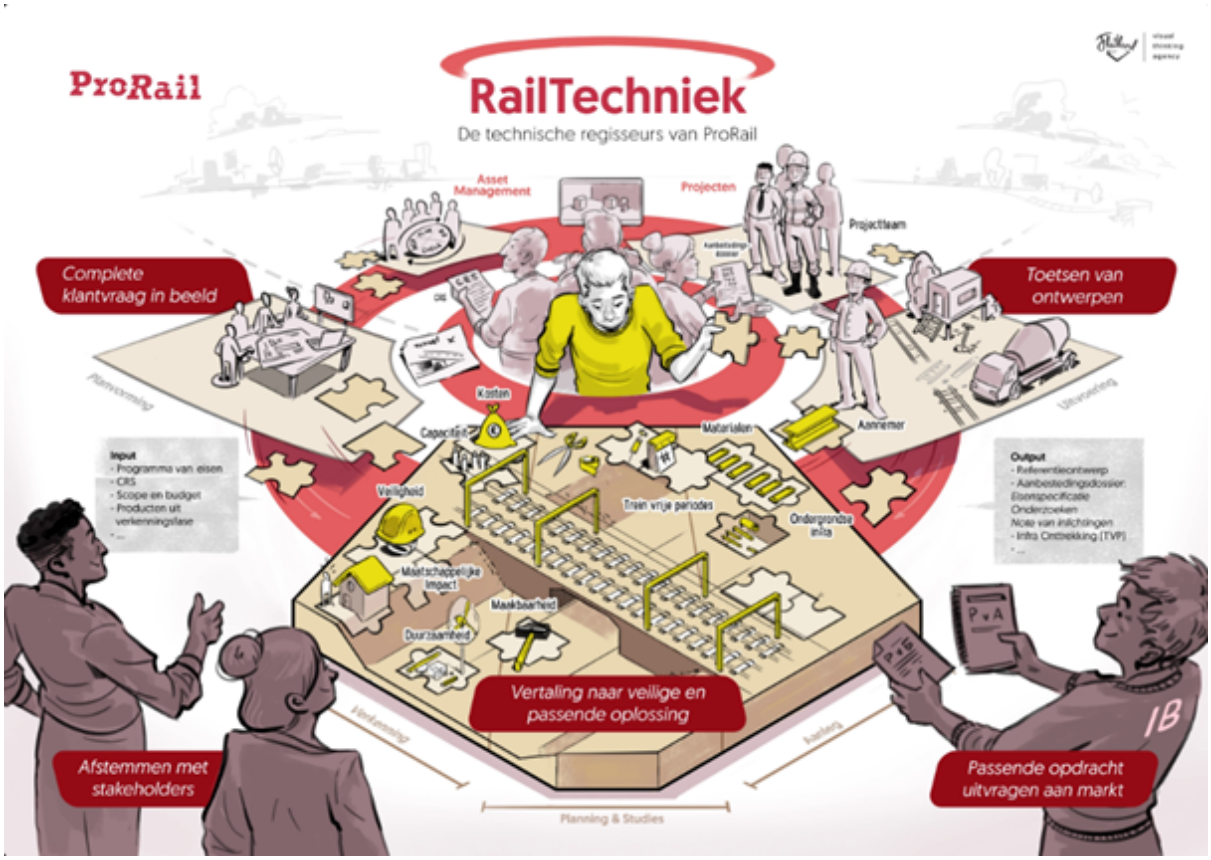


Figure 3: Visualization RailTechniek

1.1.3 RAMSHE LCM

One of the many tools used to ensure the quality of the proposed infrastructure solutions are the RAMSHE LCM analyses. RAMSHE LCM focuses on optimizing:

- Reliability (R): What is the chance that a system failure occurs?
- Availability (A): How long does it take to solve a system failure and are there alternative routes in case of a system failure?
- Maintainability (M): How easily can it be maintained?
- Safety (S): Is it safe for people in and around the infrastructure?
- Health (HE): Are there health risks for the employees?
- Environment (E): What are the effects on the environment and surroundings?
- Lifecycle Costs (LCC) of railway infrastructure: This includes, among other things, investment, operating, maintenance and rejection costs. The lifespan of a system is estimated by looking at similar existing systems.

The RAMSHE LCM procedure describes how to execute the RAMSHE LCM analyses within an infrastructure project. It consists of 14 steps, which can be performed multiple times within a project. From the start of the project, starting with the customer request, a dossier is kept and supplemented with relevant information throughout the procedure. At the end of the procedure a complete dossier is delivered containing all relevant information needed to properly organize and carry out management and maintenance from the day of commissioning.

1.2 Problem identification

This section describes the analyzed problem context. First the problem as experienced by ProRail is discussed in the initial problem statement in Section 1.2.1 after which the full problem context is described in Section 1.2.2 and a core problem is identified in Section 1.2.3.

1.2.1 Initial problem statement

The RAMSHE LCM procedure has been adjusted and updated a few times over the years, but despite the improvement aims it is still not used in a consistent manner. Even more so, it is often not even used at all. We performed a survey among multiple Technical Project Leaders (TPLs), who are considered to be one of the main users of the procedure, in order to measure the current use rate of the procedure. From the 21 respondents, 4 had never heard of the procedure and 11 deliberately do not use the procedure. This means that current use rate among the respondents of the survey is approximately 29%. We define the following action problem:

"The use rate of the RAMSHE LCM procedure should be improved."

1.2.2 Problem context

By analyzing the survey and having discussions with employees, several problems became visible. The survey results are referred to multiple times to validate the problem context. The full overview of the results can be found in Appendix A. We define four main causes for the low use rate:

Lack of knowledge of the procedure
"I will have to look into it a bit more" and "I notice that there is a lack of knowledge and experience within RailTechniek to 'do more' with RAMSHE LCM" are quotes from TPLs. From the survey respondents, 19% have indicated to not be familiar with the procedure at all. This problem directly affects the use rate as it is not possible to use a procedure when you are unfamiliar with its existence.

Low ease of use
Employees have indicated that it can be quite difficult to execute the procedure. The main reasons that have been mentioned are that the large amount of stakeholders leads to the responsibilities not always being correctly defined, a lack of knowledge about the proper execution of the procedure and a lack of clarity about how the procedure can be applied to a specific situation. Lastly, employees rate the clearness of when the procedure should be used with an average 4.25 (out of 10).

High perceived effort
Another barrier for using the procedure is that the effort it takes is perceived quite high. Three problems have been found that influence the perceived effort. Firstly, the created dossier includes too many unimportant matters. "Too much information is gathered, which hinders the creation of a well-structured dossier." Secondly, there are too many and too extensive instruction documents. For example, there is a step-by-step document which is 30 pages long and another guideline document which is 60 pages long. Lastly, 44% of the respondents experience that there is some overlap within the activities in the procedure causing unnecessary double work.

Purpose of procedure not clear
From the survey we found that 87.5% of the respondents think that the value of the procedure as a whole is not or only partly clear. In other words, they do not see the purpose and are therefore less motivated to use the procedure. "I get too little input from the projects about whether it is applied and what the experiences are." The lack of a clear purpose also contributes to the problem of unnecessary work, since it is very hard to estimate what tasks are absolutely necessary when it is not clear how the result is used. The same applies to the dossier containing redundant information and it being unclear when to use the procedure.

The described problems and their relations have been visualized in Figure 4.

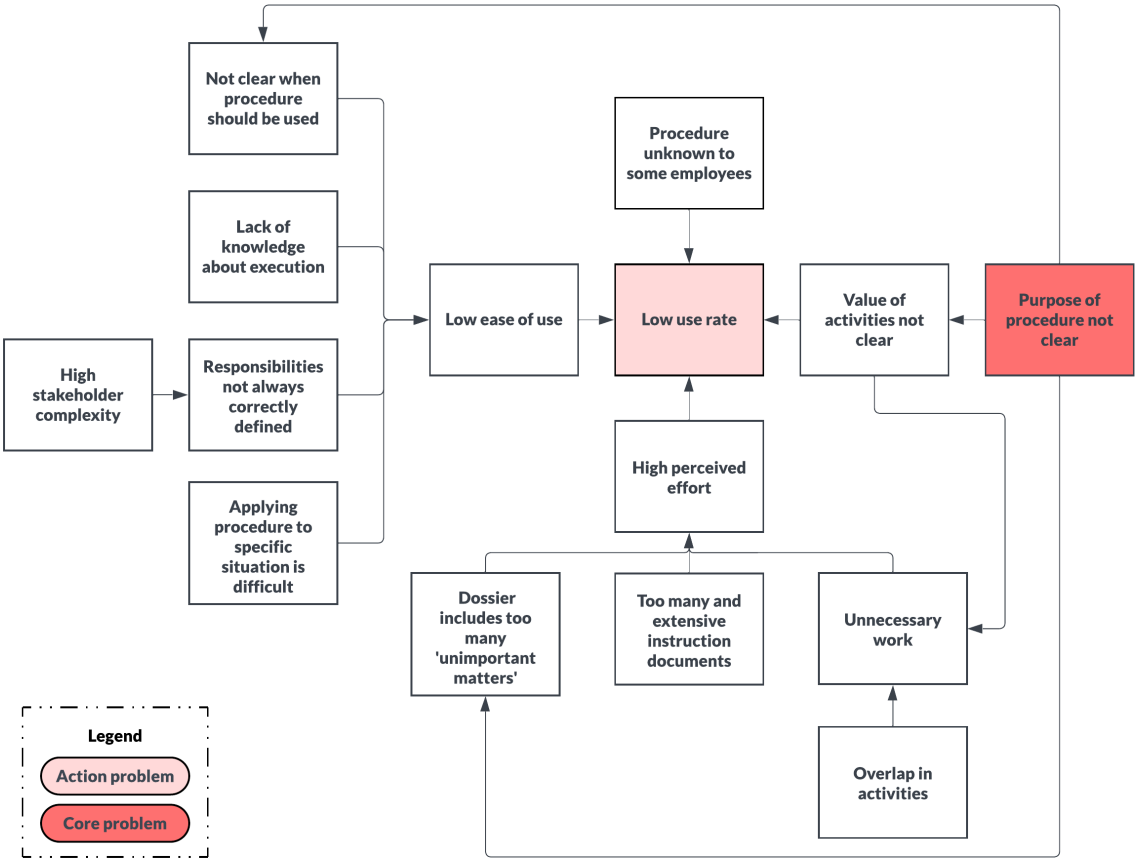


Figure 4: Problem cluster

1.2.3 Core problem

As shown in the problem cluster, there are multiple causes for the low use rate of the procedure. For the selection of the core problem that is to be tackled in this research, we took into account where the most impact could be made while adhering to the time frame of thesis assignment and where we could best put our knowledge acquired during the Industrial Engineering & Management bachelor to use.

By evaluating the different possible core problems it becomes clear that there is one core problem that plays a key role in improving the use rate of the procedure. Increasing the ease of use, lowering the perceived effort and making the procedure known to people are all necessary in order to increase the use rate of the procedure, but it will only have an actual impact when the purpose and value of the procedure is clear. After all, when the users do not know why they should use the procedure, they will not use it, even if it is easy to execute. Therefore, the selected core problem is the following:

"The value of the procedure should be identified in order to suggest improvements leading to a higher use rate"

1.3 Problem solving approach

This section elaborates on the approach that will be used to increase insight into the value of the procedure and improve its performance. In Section 1.3.1, the main research question is introduced, which will then be supported by several sub questions. The order of the sub questions will provide structure to the research. At every sub question, we elaborate on the planned activities and methods used. In Section 1.3.2 an overview of the deliverables of this research is given. Then Section 1.3.3 discusses the limitations of the research according to validity and reliability after which the practical implications of this research will be discussed in Section 1.3.4.

In this research, a Lean Six Sigma perspective will be applied. Lean Six Sigma combines the waste elimination and process improvement techniques Lean Manufacturing and Six Sigma (Zhang et al., 2012). Since the aim of our research is to identify the value of the procedure and determine improvement strategies, these techniques provide a good basis to structure our research with.

Lean methods originated form the manufacturing industry, but since then it has been proved useful in other industries as well and increasingly more literature has appeared about the application of Lean Management in different sectors. Since the RAMSHE LCM procedure is very complex and not quite comparable to standard production processes, we use the Lean perspective as a guideline, but adjust the specific methods to our own situation.

1.3.1 Research design

The main research question is formulated as follows:

"How can the use rate of the RAMSHE LCM procedure be increased while identifying the added value and eliminating waste?"

The research question contains the following key concepts:

- **Added value:** According to Hicks (2007), added value refers to "those activities that add value to either the product or service delivered by an organization and ultimately the customer".
- **Waste:** Any activity that does not add value can be identified as waste. Different types of waste can be defined and can be applied in different types of operations (Brandon-Jones et al., 2016).

The most used approach for a Lean Six Sigma project is the DMAIC methodology. It can serve as a guide for applying the Lean Six Sigma philosophy in order to improve processes, also in complex fields. DMAIC stands for define, measure, analyze, implement and control (Monday, 2022). The DMAIC cycle is shown in Figure 5. The structure of this research follows the steps of DMAIC.

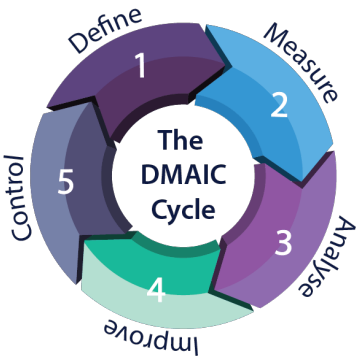


Figure 5: DMAIC cycle

Define

In the define phase, the problem and objectives are formulated and the scope of the research is determined. This is done in the current chapter. To complete the define phase, the current situation should be described and the stakeholders should be identified. The following sub-questions are created:

1. How can the current RAMSHE LCM procedure be described?

The RAMSHE LCM procedure is a very complex procedure, because it consists of many analyses involving multiple stakeholders and departments. In order to describe how it currently works, we will first gather the main documentation about the execution of the procedure in order to create an understanding of the procedure. Next, conversations with employees will be held to confirm the correctness of this understanding. By combining the existing documentation about the procedure and the employee experiences, an overview of the procedure and a description of the separate analyses within the procedure will be created.

2. Who are the stakeholders and what is their role in the procedure?

As mentioned before, there are multiple stakeholders involved in the procedure. Different stakeholders have different perspectives and experience different values. In order to identify what the intended value of the RAMSHE LCM procedure is and to put this into the right perspective, the stakes of the involved players should be identified. Therefore, a stakeholder analysis will be performed. The instruction documents of the procedure will be used to identify the different stakeholders. Semi-structured interviews will then be held with all stakeholders to analyze their role within the procedure. As a result, a stakeholder register or map will be created, which will allow us to identify the stakes of the stakeholders. The stakeholder analysis framework for Lean Six Sigma projects (Elias, 2016) is used as a basis to structure our own stakeholder analysis.

3. Which outcomes and characteristics of the procedure are valued by the stakeholders?

Before the procedure can be improved, we must know what the procedure would optimally look like. We research this by asking the previously identified stakeholders about their preferred outcomes and characteristics of the procedure. In multiple lean studies these are described as CTQs or Critical to Quality. These show the qualities that a process has in a perfect world. By factoring in the identified stakes as well as the occurrence of the mentioned outcomes and characteristics during the interviews, the outcomes and characteristics can be ranked on their perceived importance.

Measure

Next, the measure phase will be entered. The main goal here is to measure the current performance of the procedure. In the last question of the define phase, we identified what the procedure would ideally look like in the eyes of the stakeholders. In this phase, we will measure the performance on these characteristics or CTQs as well as determine to what extent they contribute to the waste within the procedure.

4. How can the performance of a procedure be measured in a lean perspective?

We will perform a literature search to determine which techniques are most suitable for measuring the performance of a procedure.

5. What is the current performance of the procedure?

Here, the actual measurement will take place based on the literature review of the previous question and the CTQs found during the stakeholder interviews.

Analyze

After measuring the performance of the procedure, the analyze phase will be entered. The following question will be answered:

6. What are the main bottlenecks within the procedure?

To answer this question, we analyze the results from the measure phase. We do this by answering the following sub-questions:

- What bottlenecks can be identified?

  Here we define all the possible bottlenecks that negatively impact the performance of the procedure.

- Which bottlenecks should be tackled first?

  We make a selection of the bottlenecks that should be tackled first by comparing the different bottlenecks using the results of the measure phase.

- What are the root causes of the selected bottlenecks?

  Here we perform a root cause analysis on the selected bottlenecks.

Improve and control

Next, the improve and control phases will be entered. Generally, these phases include addressing root causes and eliminating issues leading to waste, as well as ensuring that the solutions are sustainable. The following sub-question is defined:

7. What methods can be used to address the root causes?

Once it is clear which bottlenecks need to be tackled and what their root causes are, a plan can be created on how to tackle them. Lean improvement techniques will be used. Discussions will be held with Asset Management in order to assess the feasibility of the improvement methods. Furthermore, we identify what waste is reduced by implementing the proposed improvements. The result will be an improvement plan.

1.3.2 Deliverables

This research provides ProRail with the following deliverables:

- A stakeholder analysis
- Identification of the value of the procedure
- A bottleneck analysis
- An improvement plan with implementation advice

1.3.3 Limitations

This section elaborates on the limitations that might occur during this research by discussing validity and reliability.

Validity discusses the extent to which the research measures what we actually wish to measure (Cooper and Schindler, 2014). The most important measurement of our research will be that in the measure phase. By first clearly defining the procedure, performing a stakeholder analysis and defining the desired output and characteristics of the procedure, we will have gathered all the necessary information from ProRail to be able to create a measurement of the value within the procedure. However, the literature review in the measure phase is still very important in order to validate the measurement and to prove that we actually measure what we want to measure.

Reliability discusses the accuracy of the measurement procedure (Cooper and Schindler, 2014). Since there are only ten weeks to perform the research, it is not possible to perform the same research a second time to find out whether we will find the same results. However, we can think about what would happen if we were to perform the research a second time at a later date. ProRail is currently already working on a new version of the procedure as well as creating courses for employees on how to use the procedure, which will have an influence on the results. Our research would still measure the value that the procedure adds, but the specific activities as well as employee experiences would differ, so the outcome could be different.

1.3.4 Relevance for science and practice

The research will contribute to knowledge on how very extensive processes involving many stakeholders can be mapped and analyzed. This could have a relevance to science as there are currently many theories on how to do this with mostly quantitative processes in manufacturing industries for example, but there is not yet many information on how to do this with processes that mostly involve information flows. Furthermore, the research could have a big impact on the practice of ProRail, since the RAMSHE LCM procedure should be applied during many infrastructure projects.

Chapter 2: Define

In this chapter, we execute the define phase by sketching an overview of the current state of the application of RAMSHE LCM. Section 2.1 describes the application of RAMSHE LCM within the context of ProRail. In Section 2.2 a stakeholder analysis is performed. Lastly, in Section 2.3 the desired outcomes and characteristics of RAMSHE LCM procedure are defined.

2.1 Current situation

Following the research design as explained in Section 1.3.1, the following question will be answered first:

D1: *"How can the current RAMSHE LCM procedure be described?"*

We answer the question by touching upon the following sub-questions:

- What documentation is available within ProRail about the execution of RAMSHE LCM?
- What are the separate analyses that RAMSHE LCM is based on?
- How does the application of RAMSHE LCM fit into the operations of ProRail?
- What does the current procedure look like?

2.1.1 Available documentation

There are two important sources from which we retrieved the relevant information and documentation about the application of RAMSHE LCM. This is the general sharepoint and the Rail Infra Catalogus. The sharepoint allows you to quickly find information on many different topics and shows the connections between the different departments. The Rail Infra Catalogus can be found on the sharepoint and contains current procedures, documents, products and drawings that are used by employees. Since the goal is to create an accurate overview of the procedure as a whole, we do not take into account all the separate templates and tools that are used to execute the separate RAMSHE LCM analyses. An overview of the selected documents is shown in table 2. The information in these documents is used to further sketch the context of RAMSHE LCM.

Document	**Description**	**Type of data / relevance**
HDL00032-V002 (Leidraad voor RAMSHE-LCM studie)	Elaborate 64-page document on RAMSHE LCM-studies within ProRail.	Motivation, context, specific analyses, KPIs, 11-step guideline.
PRC00290-V002 (Stappenplan RAM)	Detailed step-by-step plan on the execution of the RAM procedure.	Activities, stakeholders, responsibilities, required input and output.
Kernproces Informatieoverzicht HSWI project	Process used in every large infrastructure project executed by ProRail. Also includes all tools and information needed for decision making.	Visual link between RAMSHE LCM and infrastructure projects.
PRC00055-V011	Procedure that describes the establishment, recording and monitoring of the implementation of the agreements between the management and project organizations. It is required when ProRail AM will manage the infrastructure.	Links with RAMSHE LCM and several protocols within PRC00055.

Table 2: Selected documentation

2.1.2 Separate analyses

According to the 'leidraad voor RAMSHE-LCM studie', the analyses within RAMSHE LCM are the following: RA, M, S, H, E and LCC. The LCM that is mentioned in the name combines all these analyses to make a prediction on the life cycle management of a system. We shortly elaborate on the separate analyses:

RA-analysis (Reliability and Availability):

With an RA-analysis, the operational reliability of a system is calculated. The operational reliability refers to the influence on the reliability and availability of a railinfra system: how often can the objectives of the specific infra not be realized because of a system failure and how long does such a failure last? An objective could for example be a certain percentage of trains that should arrive on time. Different failure causes can be selected for analysis, depending on the goal of the analysis.

M-analysis (Maintenance):

The M-analysis has been created in order to be able to determine the length of repair times before a system is functional again. Next to items like the planned unavailability, the output of the M-analysis can also contain the following items: An overview of the required maintenance facilities, the change in costs of maintenance (preventive as well as corrective) and an estimation of the lifespan of the components, and lastly a maintenance plan.

SHE-analyses (Safety, Health & Environment):

For these aspects, ProRail has developed extensive regulations based on European and Dutch legislations. These aspects often have some overlap. With the safety analysis, the safety of the system with regards to people in and around the infrastructure system is being mapped. The health analysis discusses the extent to which a process is free of risks for human safety, human health and the wellbeing of everyone that is directly related to the system. The health analysis differentiates itself from the safety analysis by specifically focusing on the work situation. The environment analysis concerns itself with esthetic aspects like ecology, noise disturbance and sustainability.

LCC-analysis (Life Cycle Cost):

With this analysis, the entire life cycle costs of the different variants of new rail infrastructure can be determined in order to compare them. Costs that fall under the total life cycle costs are investment costs, operating costs, rejection costs (if the project is cancelled) and residual value (the value of an object when it is no longer in use).

2.1.3 Connection with ProRail operations

Now that the basis of the procedure (the analyses) is described, we will elaborate on how it is connected to the operations within ProRail in order to clarify when the procedure should be used. As shown in Table 2, there were two documents that clearly linked the analyses to the operations of ProRail. These are the Kernproces and PRC00055. We start with elaborating on the first mentioned.

Kernproces HSWI (Hoofdspoorweginfrastructuur) - projects concerning new or changed railinfra

In order to successfully manage an infrastructure project, several decisions should be made together with multiple parties before the actual realization of a complex project can start. The Kernproces gives insight into how ProRail tackles their projects and which products and information are necessary for decision making. There are different versions of the Kernproces based on the type of project. We consider the version which focuses on projects in which a change in function (functiewijziging) occurs, since RAMSHE LCM analyses are only necessary when something new is designed. The RAMSHE LCM analyses are not required in projects that only focus on function retention (functiehandhaving).

A visualization of the phases within the Kernproces is shown in Figure 6.

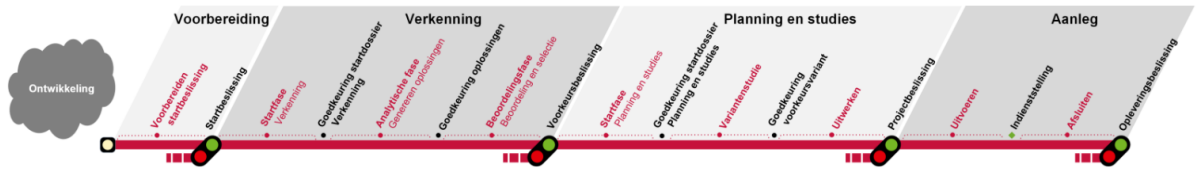


Figure 6: Phases Kernproces

As shown in the figure, the Kernproces exists out of four different phases. These are preparation, exploration, planning & studies and construction. The goal of the **preparation phase** is to identify, research and concretize the assignment in order to decide whether the project should be executed. At the end of this phase, the start decision is made. The making of the start decision acts as the starting signal of the **exploration phase**. Here, the goal is to explore different solution approaches in order to select the best solution. In this case a solution is still quite broad and can be simply seen as the entire change to the current infra or the new infra that needs to be build in order to achieve the project goals. Once a solution has been selected, the **planning & studies phase** will start. The main objective of this phase is to make sure that the realization of the solution is legally and financially feasible. The preferred solution from the exploration phase is expanded by creating and studying different variants of the solution. For example, if new rails should be placed, there are different materials that can be used. One preferred variant will be selected to be further developed. Lastly, the **construction phase** is entered. Here, the plans created in the planning and studies phase will be executed. The essence of this phase is to achieve a successful execution, transfer and closure.

An explicit decision about the continuation of the project is made at the end of every phase except for the construction phase, here a decision is made on whether the quality of the new infra is sufficient and can be made operational. Next to these decisions, internal decision making should be performed at the end of every subphase as well. For example, within the exploration phase, several decision making dossiers should be created before you can move from the start phase to the analytical phase and subsequently to the judgment phase. One of these types of information input is RAMSHE LCM. It helps with making sure that the infrastructure is designed for a full lifespan and is therefore integrated into the Kernproces along with other topics such as Value Engineering and Sustainability. According to the 'kernproces information overview', there are four instances in which RAMSHE-LCM is required as input for the Kernproces. We have visualized this in Figure 7. The full information overview which also shows the other information input can be found in figure B in Appendix B.

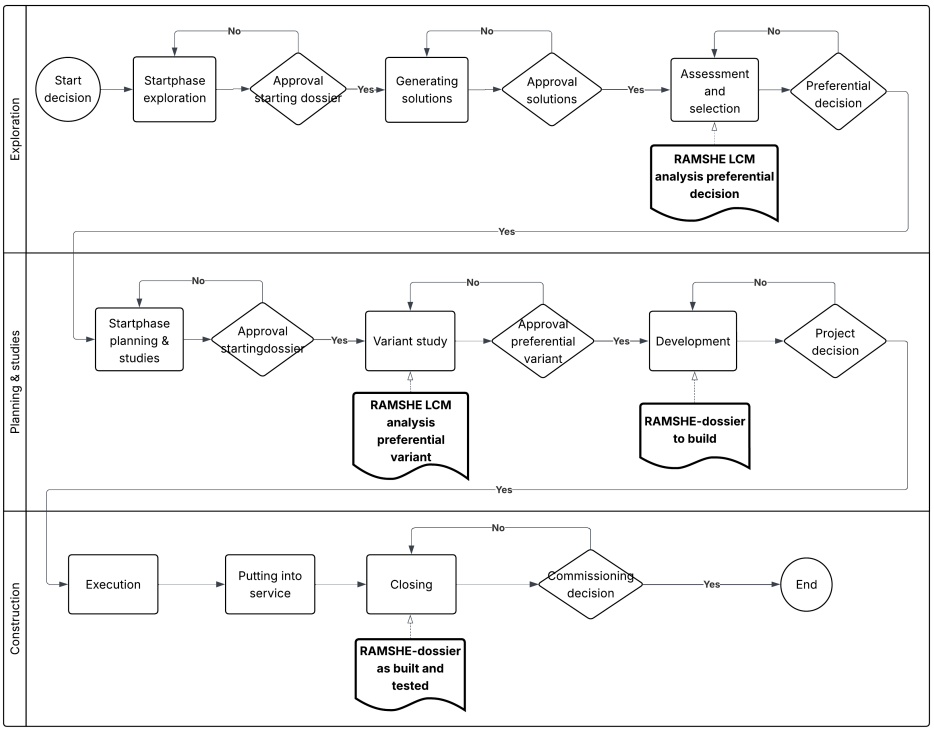


Figure 7: Flowchart RAMSHE dossier

PRC00055 - protocols to be used during a project

PRC00055 was created to help organize the collaboration between the organizations of Asset Management and Projects. It consists of several protocols. The protocols are all connected to a certain phase within the Kernproces. In several of the protocols the involvement of RAMSHE LCM is mentioned. However, for the actual execution of RAMSHE LCM it refers to HDL00032 and PRC00290. We elaborate on those in the next subsection.

2.1.4 Procedure

The activities that take place in the execution of RAMSHE LCM can be described in two different ways: By looking at the separate analyses or by looking at the steps in the written procedures. During an interview with two employees who are specialized in the topic and from our initial problem analysis, we concluded that the problems are mainly within the procedure itself rather than within the separate analyses. Since the procedure should be improved, we describe the current situation based on the current procedure. Therefore, the current procedure should be defined and clarified.

As shown in Table 2, there are two documents in which an actual procedure is mentioned. We shortly touch upon the differences:

The **'Leidraad voor RAMSHE – LCM studie'** has been published in December 2010 and since then no newer version has come out. In 64 pages it elaborately discusses the separate analyses that are part of the RAMSHE – LCM study and their use. It also provides an eleven-step plan, which can serve as a procedure on how to use the RAMSHE LCM analyses in every phase of a project.

The **'Stappenplan RAM'** has last been revised in 2021 and consists of 18 pages. The goal of the 'stappenplan RAM' is similar to the eleven-step plan as described in the 'leidraad voor RAMSHE-LCM studie', but slightly differs in content as the steps are more elaborate and responsibilities are clearly defined with RASCI-tables. RASCI stands for Responsible, Accountable, Supports, Consulting and Informed and shows employees the role that they have within a certain step. Furthermore, at every step

the connection to the Kernproces is shown.

Selected procedure

There are multiple documents in which a slightly different explanation is given on how and when to execute RAMSHE LCM within infrastructure projects, differentiating from very detailed to leaving it open to interpretation and personal preference. We conclude that this is not helpful to the usability of RAMSHE LCM and that only one procedure should be used.

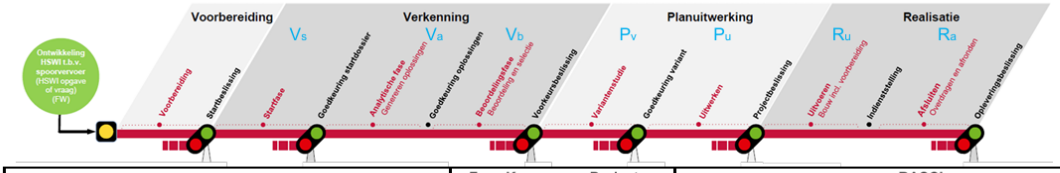
In this research, the activities described in PRC00290-V002 will be seen as the actual activities of the procedure since these have the most detailed description and this document has been written with the sole purpose of defining the steps that need to be taken in order to include RAMSHE LCM in a project, whereas the other documents also include many other procedures or do not have a specific enough description of a procedure.

A visual representation of the procedure including the separate steps, responsibilities and connection to the kernproces projecten is shown in Figure 8.

Steps in PRC000290.V002

ProRail Stappenplan RAM PRC00290

Bijlage 1 Koppeling van stappen aan het kernproces projecten en RASCI



Stap in RAM–LCM proces	Fase Kernproces Projecten							RASCI								
	Vs	Va	Vb	Pv	Pu	Ru	Ra	Plan co	PLON	RSE	Proj Mgr	Gebied Mgr DO	Gebied Mgr AO&I	Gebied Mgr CM	ON	Bouw Mgr
1. Beoordeel de wijziging, analyseer en beoordeel de risico's								S	R		A	C	C	C		
2. Richt het RAM proces in								S	R	R	A	C				
3. Neem RAM analyses op in contractering van engineering		22	22	22	22	23		I	R	R	A				C	
4. Stel de RAM eisen op								S	S		A	R	R	R		
5. Beschrijf de V&V methode van de CRS en SRS eisen								R	S	S	A	C	C	C		
6. Ontwerp het systeem (ontwikkelen van oplossingsrichtingen, alternatieven en varianten)								C	R	R	A	C	C	C	S	
7. Verifiëren en valideren RAM eisen in ontwerp t.b.v. alternatief en variant afweging								I	R	R	A				C	
8. Opstellen van de SRS-eisen								C	R	R	A	C	C		C	
9. Update van bestaand RAMSHE-LCM "to build"								I		R	A				C	
10. Opnemen van RAM eisen in aanbestedingsdossier voor de bouwende aannemer								I		R	A				C	S
11. Verifieer en valideer RAM eisen in gerealiseerd systeem										S	A	I			S	R
12. Accepteer gerealiseerd systeem											A	S				R
13. RAMSHE-LCM dossier overdragen aan gebiedsmanager DO							23	I		S	A/R	C	I			S
14. Beheer, onderhoud en prestatiemonitoring											A/R				S	

[22] Hangt af van contractering strategie
[23] Wel bij D&C, niet bij E&C, Construct en BBV

Procedure versie 002 pag. 15/18

Figure 8: Stappenplan RAM

The procedure is described in 14 steps. It is important to note that this is not a sequential process, since some steps are gone through multiple times during a project. Figure 8 summarizes the procedure by showing the separate steps, the connection to the phases of the Kernproces and a description of the responsibilities per step. In the complete document, the separate steps are elaborated on by mentioning the goal, a description, the needed input and the output that should be delivered.

The responsibilities of the steps are shown with a RASCI matrix. It describes who is responsible (R), accountable (A), supporting (S), consulting (C) and informed (I).

The procedure starts with evaluating the goals and estimating whether the change in the rail infras-

tructure could have an effect on the RAM performance. It is then determined which RAM analyses can be performed and how they should be executed. An overview is then created with the steps that have to be taken to adhere to the RAM requirements. The selection of RAM analyses and the creation of the process can happen multiple times during the entire procedure, since different analyses can be required in different phases of the Kernproces.

Asset Management is responsible that the RAM requirements are included into the Customer Requirements Specification (CRS). The Plan Coordinator is then responsible for describing the Verification and Validation methods (V&V) of the CRS requirements and the System Requirements Specification (SRS) requirements. The Plan Developer or Technical Project Leader (depending on the phase within the Kernproces) will develop solutions, verify and validate its RAM requirements and create SRS requirements.

When the SRS requirements for the selected solution are created, the 'to build' version of the dossier is created by the Technical Project Leader and the RAM requirements will be included into the tender file for the contractor. The Construction Manager will then ensure that the realized infrastructure complies with the RAM requirements from the tender file. When the expected RAM performance of the new system is communicated, the new system can be accepted. Lastly, the definitive dossier will be transferred to the Area manager Daily Operation and the RAM performance will be monitored while managing and maintaining the new infrastructure.

Type of procedure

To be able to properly analyze the performance of the procedure during our research it is important to identify what type of procedure it is. What becomes visible by looking at the different steps within the procedure is that all the input and output exist of information. Information is given as an input at every step after which it is used by for example performing analyses which in their turn generate new information which is used as input for the next step. Therefore, we can conclude that this is a procedure in which the transfer of information is central.

2.2 Stakeholder analysis

Now that the activities are defined, we discuss the following sub-question:

D2: *"Who are the stakeholders and what is their role in the process?"*

Literature on Lean Six Sigma projects suggests that the success of Lean Six Sigma projects is heavily dependent on its stakeholders, which is why an elaborate stakeholder analysis is required (Elias, 2016). Furthermore, in a research on improving corporate communications by using Lean Six Sigma, Barnes and Walker (2010) suggest that one of the key parts in the define phase of DMAIC should be to 'define stakeholders and what they care about most'. They mention that by using surveys, focus groups or similar techniques, the 'voice of the customer' must be assessed in order to determine which outcomes are desired and are 'critical to quality', also called 'CTQ'. We apply this to our situation by looking at the procedure as the product and the users of the procedure as the customer. A list of CTQs will sketch an image of what the procedure would optimally look like.

Before we can create a list of CTQ's, the stakeholders need to be defined and their needs assessed. Elias (2016) has created a stakeholder analysis framework that is suitable for Lean Six Sigma project management. This framework consists of ten separate steps divided into several phases. We will go through the first three steps which are all part of the 'rational-level stakeholder analysis' phase. The remainder of the steps are not tackled as they focus on stakeholder management during the execution and improvement phases of a project. These topics do not belong to the define phase of our research.

1. Develop a stakeholder map for the Lean Six Sigma project

With the stakeholder map, a general overview can be sketched of the stakeholders that are involved with and/or play a role in the RAMSHE LCM procedure. We identified the stakeholders by analyzing the

documentation on the RAMSHE LCM procedure and consulting several organigrams of the departments within ProRail. The stakeholder map is shown in Figure 9. It shows the involved departments.

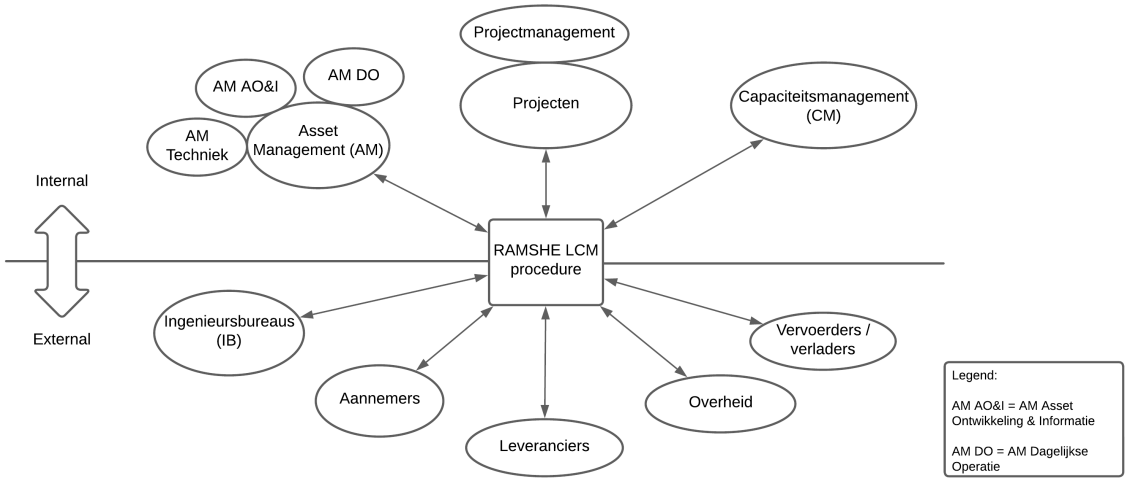


Figure 9: Stakeholder map

2. Prepare a chart of specific stakeholders for the Lean Six Sigma project

After defining the stakeholder departments/groups, a specific stakeholder chart can be created. Here, more specific stakeholders for the groups in the stakeholder map are identified. The stakeholder chart can be found in table 3. The internal stakeholders are on the left and the external on the right side of the table.

Specific stakeholders	
AM Asset Development & Information	*Contractors*
Area Manager	
AM Techniek	*Government*
Technical Project Leader	Ministry of Infrastructure and Water Management
	Regional governments
AM Daily Operation	*Suppliers*
Area Manager	
Projectmanagement	*Engineering Firms*
Plan Developers	
Projectmanagers	
Construction Managers	
Capacity Management	*Carriers/shippers*
Area Manager	

Table 3: Specific stakeholders

3. Identify the stakes of stakeholders of the Lean Six Sigma project

The last step in the stakeholder analysis is to identify the involvement and interest of the stakeholders in the procedure. We measure this in terms of stakes. A stake is often defined as the level of interest in the

succeeding of the project, so we define the stakes by looking at the level of interest in the improvement of the RAMSHE LCM procedure. The stakes are either low (*), medium (**) or high (***). The identified stakes of the stakeholders are shown in Table 4. The decision was made to not include the external stakeholders (shown on the right side of Table 3), since they do not have an executing role within the procedure. For example, the government and carriers are involved by providing input in the form of a customer request, but do not actively participate in the procedure. The engineering firms (ingenieursbureaus) execute assignments that are specified by ProRail, but also do not actively participate in the procedure. The stakes have been researched by having conversations with the selected stakeholders and by using the input from the RASCI matrices as shown in Figure 8. For example, the TPL plays a role in ten out of the fourteen steps and is the main responsible for seven of those. The Area manager CM is only involved in four steps and is the main responsible in one step. The TPL therefore has a higher stake than the Area Manager CM.

Stakeholder	**Role (within procedure)**	**Stakes (* - ***)**
Plan Coordinator	Identifies the effect of the project on the RAM performances. Creates RAM requirements for CRS (see page 18/19).	**
Plan Developer	Setting RAM requirements and evaluate goals, design RAM process, ensures the creation of designs, checks RAM performance of designs.	***
Technical Project Leader	Identifies which analyses are needed, ensures the creation of designs, checks the RAM performance of the different designs, creating the RAMSHE-LCM 'to build' dossier, ensuring that the RAM requirements are included in the tender file.	***
Projectmanager	Accountable for the execution of all steps, but not actively executing.	**
Construction manager	Making sure that the RAM requirements are adhered to during the build phase.	**
Area manager CM	Providing information from area teams to help with setting requirements. In reality mostly delegating.	*
Area manager AO&I	Providing information from area teams to help with setting requirements. In reality mostly delegating.	*
Area manager DO	Responsible for accepting the new system. In reality mostly delegating.	*

Table 4: Stakeholder Roles and Stakes

Remark: The described roles cover the main activities of a certain role, but not do not cover every single responsibility. For this, one can look back at Figure 8.

2.3 Desired outcomes and characteristics

As mentioned in the introduction of Section 2.2, the stakeholders' desired outcomes and characteristics of the procedure should be investigated to create a list of CTQ's (Critical To Quality). The CTQs can be used in the measure phase to measure the actual performance of the procedure. The following question is central to this section:

D3: *"What should be the outcomes and characteristics of the procedure?"*

We conducted a semi-structured interview with every stakeholder as identified in Table 4. The used interview guide can be found in Appendix C. Several CTQs were identified and ranked based on occurrence in the interviews. The results are shown in Table 5.

Remark: Due to time constraints, we interviewed only one employee per function. Even though they answer based on the experiences in their function, it might be possible that other employees in the same function would answer differently.

Since the core problem of this research is that the value and/or purpose of the procedure does not seem clear, we first asked the stakeholders what the purpose of the procedure is in their eyes. In other words: why should the procedure be executed? A goal that was mentioned by all stakeholders was that the procedure should help with proving that the system is reliable, available and that it is maintainable (including information about how it should be maintained). Both the Area manager Capacity Management and the Plan Coordinator added that the RAM performances help showing clear results to the decision makers and enable ProRail to steer into a certain vision.
The different perspective of the stakeholders also became clear in the answers that were given. The main goal for the Technical Project Leader for example was to ensure that a new system can be built safely. According to the Projectmanager, the main goal is to help with decision making within a design process. The Plan Coordinator answered similarly by stating that one of the goals is to help with making decisions in time in order to reduce costs in the future. This also matches the description given by the Plan Developer who believed the goal was to define the RAMSHE aspects in order to achieve low costs during life cycle management (LCM).

We combined the findings into the following statement about the purpose of the procedure:

The procedure should timely prove the required reliability, availability and maintainability of a new system in order to make the right decision ensuring low life cycle costs while adhering to the vision and regulations of ProRail.

According to the 'Leidraad voor RAMSHE LCM studies', there are three main reasons for applying RAMSHE LCM. These are the following:

- To support decision making about alternatives and the evaluation of different options within alternatives;
- To estimate the future behavior (the performance and costs) of a system;
- To prove that the system complies with internal and external regulations concerning safety and the environment.

We conclude that the goal of the procedure is quite clear among the interviewees, since the the perceived purpose from their perspective closely corresponds to the purpose as stated in the official documentation. However, since the procedure is still not used as often it should be, it suggests that the value is still not clear and that there are bottlenecks within the procedure.

To understand why the procedure is still not used often, the next step is to understand what characteristics the procedure should have according to the selected stakeholders. The following desired characteristics of the procedure were found:

- **Accessible:** The procedure should be easy to find/accessible.
- **Transparent:** It should be clear what the progress is and what phase the procedure is in at a given time.
- **Simple:** The phrase "Keep it simple stupid", also known as the KISS principle, has been mentioned multiple times during the interviews. The procedure should be easy to understand.
- **One perspective:** The procedure should not leave room for own interpretation. There should be one perspective on the execution.
- **Sufficient knowledge:** Everyone that has a responsibility within the procedure should have sufficient knowledge about the execution of their role in the procedure.
- **RAM performance input available:** Input about the desired RAM performances should be given at the start of the procedure.

- **Input received on time:** Every separate step within the procedure requires its own input. The input for the different steps within the procedure should be delivered on time.
- **Input complete:** The input for the different steps within the procedure should be complete.
- **Flexibility:** It should be possible to adjust the procedure to specific situations.
- **Executable steps (feasibility):** The execution of the steps should be feasible; if something cannot be quantified, it should not be required.
- **Monitoring:** The execution of the procedure should be monitored.
- **Sufficient work capacity:** There should be enough time (work capacity) for the execution of the procedure.
- **Concise dossier:** The RAMSHE dossier should be as concise as possible and only contain the necessary information.
- **Dossier available as input:** The RAMSHE dossier should always be transferred, managed and stored in an accessible place so that it can be used again later as input for a new project.
- **Use of dossier communicated:** It should be communicated how the definitive RAMSHE dossier is used after it is transferred to Asset Management at the end of the procedure.

To show the perceived importance of the different CTQs, an overview has been created of how often a certain CTQ has been mentioned and by whom. The CTQs were all mentioned spontaneously during the interview, which is why 'Sufficient knowledge' for example is not mentioned by all interviewees, while they probably do all find it very important. The results therefore show what CTQs are most on the interviewees' minds. The overview can be seen in Table 5. The abbreviations used are the following:

- PLON = Planontwikkelaar (Plan Developer)
- TPL = Technisch Projectleider (Technical Project Leader)
- Planco = Plancoördinator (Plan Coordinator)
- Proj.mgr. = Projectmanager
- Bouwmgr. = Bouwmanager (Construction manager)
- CM = Gebiedsmanager Capaciteitmanagement (Area manager Capacity Management)
- AO&I = Gebiedsmanager Asset Ontwikkeling & Informatie (Area manager Asset Development and Information)
- DO = Gebiedsmanager Dagelijkse Operatie (Area manager Daily Operation)

We notice that the amount of CTQs mentioned in the interviews corresponds to the identified stakes in Table 4. The PLON, TPL and Planco mentioned relatively many CTQs compared to the other stakeholders while they also have the highest stakes.

The CTQs that have been mentioned the most are the sufficient knowledge, that it should be simple and the availability of the RAM performance input. The fact that sufficient knowledge is mentioned most is not surprising, since one of the first issues we found with the procedure was the fact that there were many people that did not know about the procedure. Furthermore, some of the interviewees themselves also had to dig deep before they recognized the procedure or did not even recognize it at all. Next to a lack of knowledge, we also defined the low ease of use and high perceived effort in our initial problem analysis in Section 1.2. That the procedure should be simple closely corresponds to the perceived effort and availability of the RAM performance input corresponds to the ease of use, since a lack of input makes it very difficult to efficiently use the procedure. In short, the top 3 mentioned CTQs closely correspond to what was expected.

The CTQs that were mentioned the least often are that the procedure is accessible, that the input is received on time and that the input is complete. This seems quite strange since these CTQs all seem essential for the performance of the procedure: it cannot be executed well when it is not accessible or when the input is missing or received too late. A reason that these CTQs are only mentioned once could be that they are so obvious that the interviewees did not think to specifically mention them.

CTQ / interviewee	PLON	TPL	Planco	Proj. mgr.	Bouwmgr.	CM	AO&I	DO	# mentions
Sufficient knowledge		x	x	x		x	x	x	6
Simple	x	x	x		x	x			5
RAM performance input available	x	x	x			x			4
Use of dossier communicated	x	x	x						3
Concise dossier	x	x	x						3
Sufficient work capacity	x				x		x		3
Monitoring		x	x	x					3
Flexible			x		x				2
Executable steps (feasible)	x					x			2
Dossier available as input		x	x						2
Transparent		x	x						2
One perspective	x						x		2
Accessible			x						1
Input received on time					x				1
Input complete	x								1

Table 5: Overview of CTQs mentioned by interviewees (1 interviewee per different function)

2.4 Conclusion

In this chapter we discussed the current situation, performed a stakeholder analysis and created a list of desired outcomes and characteristics of the procedure. We shortly summarize our findings.

Current situation

The application of RAMSHE LCM within the projects of ProRail happens according to PRC00290.V002. This is a 14-step guideline which, for every step, describes the responsibilities, required input, expected output and connection to the ProRail kernproces. RASCI tables show the involved employees and their role within the specific steps of the procedure.

Stakeholder analysis

There are multiple stakeholders within the procedure who all play different roles and have different levels of knowledge about the procedure. By having multiple conversations with employees and by reviewing the documentation on the procedure, the stakes of the stakeholders have been identified and are shown in Table 4. We found that the highest stakes belong to the Plan Developer and the Technical Project Leader, followed by the Plan Coordinator, Construction Manager and Project Manager. The Area managers of CM, AO&I and DO have the lowest stakes as they are responsible on paper, but in reality delegate most of their work in the procedure.

Desired outcomes and characteristics

Semi-structured interviews have been conducted with the different selected stakeholders to identify the perceived purpose of the procedure as well as the characteristics that are critical to quality (CTQ). The perceived purpose of the procedure closely corresponds to the purpose as described in the documents on the procedure. We summarized the perceived purpose of the interviewees as follows:

The procedure should timely prove the required reliability, availability and maintainability of a new system in order to make the right decision ensuring low life cycle costs while adhering to the vision and regulations of ProRail

Fifteen different CTQs have been found and ranked based on the occurrence in the interviews. Most mentioned were that there should be sufficient knowledge on how to execute the procedure, that the

procedure should be kept simple and that the RAM performance input is available, meaning that clear RAM goals are provided at the start of a project.

Next

The goal of this chapter was to create a good understanding of the current procedure and what characteristics are critical to the quality of the procedure so that the actual performance can be measured in the next chapter. By researching the relevant documents, performing a stakeholder analysis and identifying the desired outcomes and characteristics a good basis has been created for the measurement of the performance. In the next chapter, the actual measurement of the performance of the procedure is tackled.

Chapter 3: Measure

This chapter begins with a literature search in Section 3.1 what ways there are to measure the performance of the RAMSHE LCM procedure. In Section 3.2, we discuss how we can apply the literature to our research and Section 3.3 discusses how we actually measure the current performance of the procedure. In Section 3.4, the results are shown after which they are shortly discussed in Section 3.5.

3.1 Literature search on performance measurement

In order to determine how the performance of the procedure can be measured, we answer the following knowledge question:

M1: *"How can the performance of a procedure be measured in a lean perspective?"*

During earlier orientating research, it became clear that most of the research on lean approaches of measuring process performance are written about the manufacturing industry. However, the RAMSHE LCM procedure does not so much create a product, but more so it creates information as also shortly discussed at the end of Section 2.1.4. In this chapter, some literature searches are performed. Since the identification of waste is a key part of almost all lean research, we start by researching what waste we can identify in our research. With the keywords "Lean information management" and "waste", three relevant sources were selected on the application of lean management from a perspective of information management.

3.1.1 Information waste

Lean is originated from production and its origin can be found in the Toyota company in Japan. The term lean is therefore also derived from lean production Bertagnolli (2022). The main objective of lean is to create waste-free processes Bertagnolli (2022). Hicks (2007) argues that lean thinking is also applicable to information management. According to Hicks (2007), information management involves enabling information (which he identifies as the value) to flow to the end-user (or the information customer) through the processes of exchange, sharing and collaboration.

Information waste is the main concept that is used to identify and measure process inefficiencies (Verhagen et al., 2015). The traditional model of lean thinking defines seven manufacturing wastes: Overproduction, waiting, processing, defects, transport, inventory and motion. Based on these traditional wastes Hicks (2007) has defined four types of waste in the context of information management and provided examples of a set of issues that can be classified under these types of waste. Since this is the first ever translation of wastes into the area of information management, we mention the definitions of Hicks first. The types of waste are:

- **Failure demand:** Necessary to overcome a lack of information;
- **Flow demand:** Spent trying to identify the information elements that need to flow;
- **Flow excess:** Necessary to overcome excessive information;
- **Flawed flow:** Necessary to correct or verify information.

Verhagen et al. (2015) has also defined types of information waste, but in contrast to Hicks (2007), all the traditional seven wastes defined by lean manufacturing are translated to equivalents of information waste. The types of waste are:

- **Overproduction**: Time and resources necessary to create excessive information and/or time and resources spent on creating unnecessary level of detail and accuracy.
- **Waiting**: Increase in lead time as a result of information that has been created and is waiting to be applied and/or increase in lead time as a result of a process actor waiting for input information to be created and shared.
- **Processing**: Time and resources needed to transform information into the desired format and/or time and resources needed to create workarounds when information is unavailable.

- **Defects**: Time and resources necessary to verify and correct provided information and/or time and resources necessary to hunt down missing information.
- **Transport**: Time and resources needed to extract information from multiple information sources, transforming and loading it into yet another information system and/or time and resources needed to convey information with the use of manual, mail or e-mail delivery.
- **Inventory**: Time and resources necessary to house and maintain redundant information and/or resources spent on redundant information sources.
- **Motion**: Time and resources spent on moving information caused by lack of collaboration and/or real-time access and/or time and resources spent on digitalizing information provided in paper form.

Verhagen et al. (2015) uses these types of waste to identify improvement opportunities by using a method that relies on quantifying information waste in engineering processes. It starts with a macro-level analysis in which the information waste within the current process is identified. Once the waste is identified it becomes possible to determine which process functions have the highest number of waste and are therefore the best candidates to be followed up with a micro-level analysis. Here the exact waste should be measured in order to generate quantitative results. The measurement will then show the process performance 'as is'. The 'as is' state should then be compared to the 'to be' state in order to determine improvement opportunities. Verhagen et al. (2015) measures the current-state process performance in terms of time.

3.1.2 Critical To Quality

Both Monday (2022) and Kowalik (2018) use CTQs or Critical to Quality in their Lean Six Sigma improvement research. During the measure phase of DMAIC, Kowalik (2018) uses the CTQs as well as Value Stream Mapping and surveys. In their paper, they describe CTQs as service features that are critical to the customers' view of quality. Examples given are staff's knowledge and convenience. While they do not directly use the CTQs to measure the process performance, they use them later on during the improve phase to create an Impact-Effort matrix. The solutions or improvements that contribute most to the CTQs are given the highest impact scores. A value stream map was created to visualize the current process and find defects in the process. Surveys were then used which included the conclusions drawn from the value stream map. The survey contained statements in which respondents could indicate their agreement with a 5 point Likert scale ranging from 'strongly disagree' to 'strongly agree'. The results of the survey showed what the biggest causes to the occurrence of problems were. According to Monday (2022) the CTQs can be used to show the gap between the 'as is' state of the process and the 'to be' state of the process. The CTQs show which qualities the process has in a perfect world. During the measure phase, the current state of the process should be assessed against the list of CTQs. The biggest gaps between the current performance and the 'perfect world' as described in the CTQs should be further analyzed to look for improvement opportunities.

In this section we asked the question "How can the performance of a procedure be measured in a lean perspective?". To summarize, information waste can be used to already identify the process inefficiencies and pinpoint the location of the biggest improvement opportunities. Furthermore, CTQs or Critical to Quality can be used to describe the 'to be' state of the procedure, which allows us to measure the gap between the 'as is' and 'to be' state. A value stream map is often used to visualize the process and find defects, however since we have previously (during the define phase) identified that the use rate of the procedure is very low, there are multiple interpretations of the procedure and many employees do not know about the procedure, we lack information to make a value stream map. A survey can be used to measure the performance of the procedure from the perspective of the employees.

We will use the CTQs that we have defined in Section 2.3 and identify which waste types they could be connected to. This gives an initial image of the type of impact that the CTQs have on the performance of the procedure. We will measure the actual performance of the procedure by transforming the CTQs into statements and including them in a survey.

3.2 Waste identification

For every CTQ the question is asked, what information waste could be found when this CTQ performs bad? The results are shown in Table 6. Table 7 shows a description of the waste and how it is connected to the CTQ. To give an example, the CTQ 'use of dossier communicated' is connected to the waste type overproduction. When it is not clearly communicated how the RAMSHE dossier is used, more information than necessary is created of which some parts are not used. In other words, there is overproduction.

As shown in Table 6, all CTQs are connected to a type of information waste. Since we do not yet know the exact extent of this waste, we include all the CTQs in the actual performance measurement. The fact that all CTQs can lead to a type of waste when performing bad, validates the fact that they are indeed very important to the performance of the procedure. The performance of the CTQs are mostly based on employee experiences, for example whether they have sufficient knowledge or have enough work capacity. A survey has therefore been selected as a tool to measure the performance of the CTQs.

CTQ / Waste	**Overp.**	**Wait.**	**Proc.**	**Def.**	**Transp.**	**Invent.**	**Motion**
Sufficient knowledge		x		x			
Simple			x		x		
RAM performance input available			x				
Use of dossier communicated	x			x			
Concise dossier	x					x	
Sufficient work capacity		x					
Monitoring				x			
Flexible	x	x	x				
Executable steps (feasible)			x				
Dossier available as input	x			x	x		
Transparent				x			x
One perspective			x				
Accessible				x			
Input received on time		x					
Input complete				x			

Table 6: CTQs and information waste

From Table 6 we find that the waste type 'defects' is most often connected with the CTQs. This means that there is a big chance that somewhere within the procedure we spend time and resources necessary to verify and correct provided information and/or time and resources necessary to hunt down missing information. The waste type 'defects' is followed by processing, waiting and overproduction. Transport, inventory and motion are less connected. Once the current performance of the CTQs is measured it becomes possible to make a statement about the actual waste in the procedure.

CTQ	**Type of waste**	**Description**
Sufficient knowledge	Waiting	Waiting on input because other employee is unaware of procedure.
	Defects	Verify and correct provided information because other employee is not yet skilled enough due to lack of knowledge.
Simple	Processing	If procedure is not simple it can take time to put information in the right formatting.
	Transport	Can take time and resources to extract info from different information sources and putting it in another system.

CTQ	Type of waste	Description
RAM performance input available	Processing	Need to create workarounds when input is not available.
Use of dossier communicated	Overproduction	If use of dossier is not clear, more information than necessary might be put in it.
	Defects	Dossier might miss information and/or provided info must be verified.
Concise dossier	Overproduction	If dossier is not concise, too much irrelevant information is stored.
	Inventory	No concise dossier leads to spending resources on maintaining redundant information.
Sufficient work capacity	Waiting	Lack of capacity leads to employees waiting on information from other employees during the procedure.
Monitoring	Defects	When there is insufficient monitoring of the execution employees themselves have to constantly verify and correct information.
Flexible	Overproduction	If the procedure is not flexible regarding specific situations, unnecessary steps may be executed generating unnecessary information.
	Waiting	When its not possible to deviate, employees are waiting unnecessarily long before they can continue with what is actually necessary.
	Processing	Takes time to create workarounds when information is not available while different (flexible) options might be possible.
Executable steps (feasible)	Processing	When a step is not executable it takes time and resources to create workarounds and/or transform the information so that it becomes feasible.
Dossier available as input	Overproduction	When dossier is inavailable excessive information is created since certain analyses have already been performed and stored in the dossier.
	Defects	When dossier is inavailable time and resources are needed to hunt down the missing information.
	Transport	Without a dossier, time and resources have to be spend on extracting information from multiple information sources.
Transparent	Defects	Without a transparent procedure, much time is spend on verifying information and hunting down missing information.
	Motion	Time and resources are spent on unnecessary moving of information because there is a lack of transparency.
One perspective	Processing	When employees have different perspectives on the execution, unnecessary time is spent on transforming the information into the desired format.
Accessible	Defects	When the procedure is not easy to find or accessible it takes time to hunt down the missing information (the procedure).

CTQ	Type of waste	Description
Input received on time	Waiting	When the input is not given on time in between the different steps, unnecessary time is spent on waiting for the input.
Input complete	Defects	When input is incomplete it takes time to verify the information and hunt down the missing information.

Table 7: Waste identification

3.3 Survey creation

A survey has been selected as the method to measure the current performance of the procedure. In this section, we shortly elaborate on the research population and structure.

3.3.1 Research population

For our research, we require input from employees that have experience using the procedure. Therefore, based on the stakeholder analysis in Section 2.2 we have selected the functions that are involved the most with the procedure. In total we contact 486 employees. These are: Technical Project Leaders (199), Plan Coordinators (8), Plan Developers (27), Construction Managers (120) and Project Managers (132).

From the initial survey that has been performed during the problem analysis, it became clear that there are some employees that have no knowledge about the procedure at all. These employees will be filtered out of the research, since we consider them unsuitable to reflect on the value of a procedure that they have no knowledge of. There are three control questions at the start of the survey that enable us to only be left with the target population, namely the employees that should have and actually have knowledge about the procedure. The next section will go into more detail on these questions.

3.3.2 Structure

The main objective of the survey is to measure the waste within the procedure by quantifying the actual performance of the procedure. The CTQs act as KPIs and the results of the survey will give us insight into their performance, ultimately leading to an overview of the current state and performance of the procedure. Table 8 gives an overview of the questions, their content and the used measurement is shown. A more elaborate explanation is given on page 32.

Question	Description	Measurement
1. Consent	Consent to participate with the research. Continue if yes. End if no.	Multiple choice
2. Function	Specification of function.	Multiple choice with open option
3. Familiarity with RAMSHE	Inform whether participants are familiar with RAMSHE. If yes, they go to question 6. If no, they continue with question 4.	Multiple choice
4. Elaboration RAMSHE	A short explanation of RAMSHE LCM.	Text block
5. Follow-up RAMSHE	Check whether participants do know RAMSHE or whether they are still unfamiliar with it after the explanation. If they are still sure they have never encountered this, end survey.	Multiple choice
6. Explanation PRC00290	A short description of PRC00290 and what it entails.	Text block

7. Experience	Check whether participants work or have worked in projects that qualify for the procedure. If no, end survey.	Multiple choice
8. Knowledge	Check whether participants know the procedure.	Multiple choice
9. Use	Check whether participants have used the procedure before.	Multiple choice
10. Active use	Ask whether participants actively use the procedure in their work. When they answer no, they have the opportunity to elaborate as to why.	Multiple choice + open text option
11. Value	Check whether the value of the procedure is clear to the participants. They can answer: yes, partly or no and the answers are to be supplemented with additional reasoning.	Multiple choice + open text options
12.Performance	Participants are asked to answer to what extent they agree with statements about the performance of the procedure.	5-point Likert scale
13. Additional explanation	Participants are given the option to give additional explanation.	Open
14. Dossier performance	Participants are asked to answer to what extent they agree with statements about the performance of the procedure. These statements are specifically about the dossier.	5-point Likert scale
15. Additional explanation	See question 13	Open
16. Importance	Participants are asked to rate the importance of the CTQs.	1-10 rating
17. Additional explanation	See question 13	Open
18. Future use	Inform whether the participants intend to use the procedure more often in the future, with the possibility of written explanation.	Multiple choice + open text option
19. Remarks	We give the possibility for last remarks or questions.	Open

Table 8: Survey structure

The survey starts with an explanation of the research and a request for consent. Once the respondents have given consent to participate in the research, they are asked about their current function, so that we are able take the different backgrounds into account during the analysis of the results.

The first set of questions is about the existing knowledge. We first ask if people are familiar with RAMSHE LCM. If they indicate that they are not familiar with it, they get a small explanation about what it entails. When they then still are not familiar with it, they are left out of the remainder of the survey.

Next we ask in what kind of projects the respondents work or have worked. In certain projects, the procedure is not used and the people that only have experience in these type of projects should therefore be filtered. They are left out of the remainder of the survey.

We then ask whether people know the procedure, whether they have used the procedure and whether they actively use the procedure. When the respondents do not actively use the procedure, they are asked to also provide the reason why they do not use it. The respondents that do not know the procedure are also left out of the remainder of the survey.

The CTQs that have been defined in subsection 2.3 to measure the current performance of the pro-

cedure have been transformed into statements. he respondents that know the procedure are asked to indicate to what extent they agree with the statements using a 5-point Likert scale. For each of the 15 statements they can answer that they Totally Disagree (TD), Disagree (D), are Neutral (N), Agree (A) or Totally Agree (TA). For example, the CTQ 'sufficient knowledge' has been transformed into the statement 'I have enough knowledge to execute my role within he procedure'. Afterwards, they are asked whether they still want to provide an additional explanation to their answers.

The choice for using a Likert scale was inspired by examples from literature. The choice for a 5-point specifically rather than a 7- or 9-point scale was to keep it as simple as possible. More options can lead to more reliable results, but they also make it harder for respondents to decide. A 5-point Likert scale allows us to get clear results while still being fast and easy to fill in for the respondents.

To measure the perceived importance of the CTQs, the respondents are asked to rate the CTQs based on how important they are for the performance of the procedure on a scale from 1 to 10. This question was added to validate whether the selected and measured CTQs actually have an influence on the performance. For example, it could be that a certain CTQ is not performing well, but employees also think that the CTQ is not relevant for the success of the procedure. The decision was made to use a 1-10 rating as a measurement since this is easily interpretable and respondents often find it easier to answer on a scale that is often used rather than for example a score from 1 to 6.

The full survey as sent to the respondents can be found in Appendix D.

3.4 Results

The results of the survey will help us answer the following question:

M2: *"What is the current performance of the procedure?"*

We visualize the results of the survey by following its structure. We first shortly discuss the response rate and the distribution of the different functions. The knowledge of the respondents and the current use rate of the procedure is then shown by discussing the results on the questions regarding these topics. We then discuss the results on the question whether the value of the procedure is clear before we dive into the results of the performance of the CTQs. At all sections, we first state the facts after which we interpret what it means.

3.4.1 Respondents

A total of 109 respondents have participated in the survey and given permission to participate in the research. We therefore have a response rate of 22%. The division of the responses within the different functions is shown in Table 9. It also shows the amount of people that were contacted per function and the corresponding response rates. For all functions except the Plan Coordinators we were able to contact all employees within that function. For the Plan Coordinators, we received a limited list of people that we were allowed to contact.

Function	**Contacted**	**Responses**	**Response rate**
Technical Project Leader	199	47	24%
Plan Coordinator	8	4	50%
Plan Developer	27	9	33%
Construction Manager	120	14	12%
Projectmanager	132	28	21%
Other*	-	7	-
Total	486	109	22%

Table 9: Respondents

*Mailing lists were used for the specific functions, but these sometimes also include some other functions, which is why there is an 'other' category.

3.4.2 Knowledge and use rate

Function	**Work in relevant projects***	**Also know the procedure**
Technical Project Leader	67%	35%
Plan Coordinator	100%	100%
Plan Developer	80%	63%
Construction Manager	57%	13%
Projectmanager	54%	36%
Other	86%	33%

Table 10: Awareness of the procedure

*Relevent projects are the projects in which the RAMSHE LCM procedure should be used. These are projects that concern new or changed infrastructure.

To be able to identify whether the knowledge of the procedure is related to the function of the respondent, we have filtered the results per function. The percentage of respondents that works in relevant projects and knows the procedure, divided into the different functions, is shown in Table 10. The high percentages of the Plan Coordinators could be caused by the fact that we received a specific list of Plan Coordinators that we could contact for our research. There is a high probability that only Plan Coordinators that have the most knowledge about the procedure were put on this list. Furthermore, what stands out is

that the Construction managers have the least knowledge of the procedure and the Plan Developer and Plan Coordinator the most.

95% of the respondents (104) said to be familiar with either RAM, RAMS, RAM-LCM or RAMSHE LCM. From these respondents 69 work or have worked in projects that qualify for RAMSHE LCM studies. The respondents that have only worked in function retention or environmental projects are filtered out of the rest of the survey by sending them straight to the end of the survey. From the remaining 69 respondents, 28 actually know about the procedure. From this group, 21 respondents have actually used the procedure before and 13 have indicated to actively use it in their work. The respondents that do not actively use the procedure have provided short explanations as to why they do this. The main reasons come down to the following:

- The respondents only have very little projects in which the procedure should be applied, but do use it when necessary;
- The respondents delegate the work;
- There are many standard components of which the LCM data is already known. Additional RAMSHE analyses are therefore not seen as value adding;
- The procedure is not generally known within the project teams.

Some explanations were too short and vague too take into account, for example "I know about its existence, but do not work with it myself" and "I'm not going to go into that now, but something about money". The complete list of answers can be found in the appendix in subsection E.1.

From the survey we found that almost all employees have heard from RAM or one of its forms, even the employees that only work in projects in which RAM analyses are not required. However, from the people that work in the projects where it is required, there are much more people that do not know the procedure than that do. From this we can conclude that even though the concept of RAM can be considered to be general knowledge among the respondents, the actual procedure which explains the execution of RAM within projects is not. When looking at the usage of the procedure, we see that most of the employees that know the procedure have used it before, but only half of them actively use it in their work. Most of the given reasons come down to the fact that they only seldom work in projects in which the procedure is actually necessary, that the work has been delegated or that they simple choose not to use it.

Remark: The results of the question whether employees actively use the procedure in their work does not portray the actual use rate as some employees interpreted this as using it often rather than always using it when necessary. Some therefore said no, while they do use the procedure whenever it is mandatory. The actual use rate is therefore derived with the following formula:

$$\text{Use rate} = \frac{\text{nr. of employees that have used the procedure}}{\text{nr. of employees that work or have worked in projects in which the procedure is required}}$$

The results of the survey once again confirm our initial problem, stating that the use rate is too low, since the use rate found in the survey is 30%.

3.4.3 Awareness of value

The following question about the value of the procedure was asked in the survey: "Is it clear to you what the value of the procedure is?". Figure 11 shows the results. When the respondents answered yes or partly, we asked them to explain their perceived value. If the answer was no we asked them to explain why the value was not clear. The full given explanations are shown in the appendix in subsection E.2.

Only the respondents that knew the procedure got asked whether the value of the procedure is clear, since it is not possible to answer that question when the procedure is unknown to you. However, by only showing the results of the respondents that know the procedure, we give a wrong impression about how clear the value is overall. Therefore, a column was added showing the clearness of the value for everyone that should use the procedure in their work. In other words, the employees that work in projects in which RAMSHE LCM should be used.

Is it clear to you what the value of the procedure is?	**Familiar with procedure (28)**	**Should be familiar (69)**
Yes	73.1%	27.5%
Partly	19.2%	7.3%
No	7.7%	2.9%

Table 11: Awareness of value

An important part of the core problem defined at the start of this research is that the value of the procedure is not entirely clear. From the results of the survey we can conclude that for most of the respondents the value was clear and by comparing their given explanation of the value to the main goals of the procedure as defined in the 'Leidraad voor RAMSHE LCM studies', which we have shown in Section 2.3, we can confirm that their understanding is correct. As also mentioned in Section 3.4.3, the full descriptions of the value that were given by the respondents can be found in Appendix E.2. There is still a relatively large amount of respondents that do not or only partly understand the value of the procedure. This is a problem for the performance of the procedure since it affects the use rate of the procedure. When the value is not clear, people are less motivated to use the procedure since they simply do not see why they should.

3.4.4 Performance of CTQs

The current performance of the procedure is measured using the previously identified CTQs. The results show to what extent the current procedure meets the expectations of the stakeholders. With a 5-point Likert scale, we measured to what extent the respondents agree with the statements that are based on the CTQs as defined in Section 2.3. The respondents could indicate that they totally disagree (TD), disagree (D), are neutral (N), agree (A) or totally agree (TA). The results are shown in Table 12 and Table 13. The CTQs have been ordered from the highest to the lowest mean. Since the mean does not paint the total picture, we also show the spread of the different answers that were given. Table 12 shows the CTQs that have to do with the dossier. The other CTQs are shown in Table 13. The additional written explanations of the respondents are shown in Appendix E.3.

The averages of the performances of the CTQs range from 1.81 for the lowest performing CTQ to 4.12 for the highest performing CTQ. Every point on the Likert scale has a numerical value ranging from 1 to 5, belonging to Totally Disagree and Totally Agree respectively. Therefore, an average score of 3 indicates that the performance of the procedure can on average be seen as neutral. We find that 9 out of 15 statements are on average disagreed on as they have a lower average score than 3. Since more than half of the statements are disagreed on we can conclude that there is still lots of room for improvement. Examples of the worst performing CTQs are: the availability of the RAMSHE dossiers as input (with 1.81), the procedure being interpreted in one way (2.31), the completeness of the necessary information/input needed for the execution of the specific steps (2.42) and the existence of specific RAM goals given as input at the start of the procedure (2.46). What is interesting is that the best performing CTQ is about having sufficient knowledge. This tells us that even though the overall knowledge of the procedure is very low (around 40%), the respondents that do know the procedure, know it very well.

Furthermore, what is interesting is that for some statements there is a high variety of answers. For example with the statement about the checking and monitoring of the procedure both Totally Disagree and Completely Agree were answered. This can partly be explained by the fact that our research population consists of five different functions, which all have different experiences. When looking at the results per function, there still is some deviation, but less than when looking at the total results. For example, it never occurs that within one function a statement has been ranked with both Totally Disagree and Completely Agree. Therefore, for the deeper analysis of the results it is important to also take into account the additional explanations that were given, since these help explain the perspectives of the different functions.

Remark: These results are retrieved from the answers of the respondents that work in the RAMSHE LCM relevent projects and actually know the procedure. In total, 26 respondents contributed to these results.

CTQ Statement	TD	D	N	A	TA	Mean	Std.dev
There is no redundant information in the dossier: it only contains information necessary for setting up management, performing maintenance and monitoring performance.	1	4	17	3	1	2.96	0.77
It is clear how and what parts of the definitive RAMSHE dossier are being used by AM	4	9	7	3	3	2.69	1.23
Existing RAMSHE dossiers are always available as input for new RAMSHE studies/projects	12	7	7	0	0	1.81	0.85

Table 12: Results procedure performance dossier

CTQ Statement	TD	D	N	A	TA	Mean	Std.dev
I have enough knowledge to execute my role within the procedure	0	2	1	15	8	4.12	0.82
It is possible to deviate from the procedure when this is necessary (at a specific situation)	0	2	6	14	4	3.77	0.82
The procedure is easy to understand	0	1	10	12	3	3.65	0.75
The procedure is easy to find / accessible	0	3	8	12	3	3.58	0.86
I have enough time to execute my role within the procedure	0	5	5	13	3	3.54	0.95
The execution of the procedure is checked/monitored	2	6	8	9	1	3.04	1.04
The result of the procedure is clearly useful and is used at different departments within ProRail	1	9	10	6	0	2.81	0.85
The described steps are always executable	2	8	13	3	0	2.65	0.80
The necessary information/input for the execution of your role within the procedure is always delivered in time	3	7	14	2	0	2.58	0.81
Specific RAM goals (the desired RAM performance of a system) are given as input at the start of the procedure	4	9	10	3	0	2.46	0.91
The necessary information/input for the execution of your role within the procedure is always complete	4	10	9	3	0	2.42	0.90
The procedure is being interpreted in the same way by the involved players	4	11	10	1	0	2.31	0.79

Table 13: Results procedure performance

3.4.5 Importance of CTQs

Respondents were asked to rate the importance of the separate CTQs on a scale of 1 to 10, where 1 means that the CTQ does not add value and 10 that the CTQ adds a lot of value and therefore has a high impact on the performance of the procedure. For example, in the case of the CTQ 'checking and monitoring' the question would then be: how important is it that the execution of the procedure is monitored? The results are shown in Table 14.

CTQs	1	2	3	4	5	6	7	8	9	10	**Mean**	**Std.dev**
Knowledge among employees	0	0	0	0	2	0	2	10	2	9	8.48	1.48
Clearness of procedure (easy to understand)	0	1	0	0	0	0	2	11	2	7	8.16	1.77
Clearness about purpose of the procedure	1	1	1	0	0	0	2	4	2	8	7.96	2.44
Feasibility of separate steps	2	1	1	1	0	1	2	6	4	5	7.60	2.84
Checking and monitoring execution	1	1	0	0	0	2	2	4	3	7	7.60	2.40
Knowledge about the use of the definitive dossier	1	1	1	1	1	2	5	4	3	6	7.44	2.43
Time available for the execution of the procedure	1	0	0	2	1	2	4	10	1	4	7.32	2.12
Availability of the needed information and input during the procedure	2	1	1	1	0	1	4	9	1	6	7.28	2.73
Availability of the specific RAM requirements at the start of the procedure	3	1	0	0	1	1	5	5	3	6	7.12	2.95
Findability of the procedure	1	1	0	1	1	2	4	6	2	3	7.08	2.02
Flexibility (easy to deviate)	2	0	1	1	2	2	2	6	2	4	7.04	2.61
Conciseness of definitive RAMSHE dossier	1	0	0	1	1	4	1	9	2	3	7.04	2.11
Timely receival of needed information and input during the procedure	2	2	0	0	0	1	5	10	2	3	7.00	2.65
Availability of existing dossier as input for new RAMSHE studies	3	1	0	0	1	1	5	8	3	2	6.76	2.70
Unambiguousness (the procedure can only be interpreted in one way)	3	2	1	1	2	3	0	6	4	3	6.24	3.09

Table 14: CTQ importance rating (incl. mean and standard deviation)

The average scores on the importance of the CTQs range between 6.24 and 8.48. The fact that all CTQs have on average scored above a 5.5, shows that they are indeed all Critical To Quality, however the difference in the results shows that some are seen as more important than others. What is interesting is that there are quite significant differences in the answers that were given by the respondents. For example, for several CTQs both 1s and 10s were given, showing that the perceived importance of the CTQ is quite personal. Three CTQs stand out because of their high scores, these are the knowledge among employees, the clearness of the procedure and the clearness about the purpose/value of the procedure. This is consistent with our previous findings during the initial problem identification in which we identified that a lack of knowledge and unclarity of the value of the procedure lead to a low use rate.

3.4.6 Impact on use rate

The last question that was asked is whether employees believe that they will use the procedure more often in the future if the value becomes clearer and improvements will be made based on the findings of this research. From the 25 remaining respondents, 76% responded yes and 24% responded no. The reasons given for not using the procedure more often came down to the fact that some respondents already use the procedure whenever necessary and therefore do not plan on using it more often. This question is of course hard to answer when it is not yet clear what the exact improvements will be, but it does give an indication about whether employees are willing to use the procedure in the future.

We can therefore conclude that, according to the respondents, for all the projects in which the procedure is relevant, the use rate will go up once the value is better known.

3.5 Discussion

In this section, we discuss our findings as well as the validity and limitations of our measurement methods. The more extensive analysis of the results in which we will analyze the root causes of the main problems as found in the survey will take place in the next chapter, which covers the analyze phase of our research.

3.5.1 Measured performance

With the finalization of the Measure phase, we have now created an overview of the current state or the 'as is' state of the procedure. In a perfect world the procedure would score perfectly on all the CTQs, meaning that the respondents would totally agree with all of the statements in the survey. Since 9 out of the 15 CTQs are disagreed on and only the CTQ about knowledge has scored above a 4 (on average agree or totally agree) there is still quite a gap between the 'as is' state and the 'to be' state of the procedure.

Now that the performance of the CTQs are measured, we can also reflect on which waste types are most likely present in the current procedure. To combine the CTQ measurements with the CTQ-waste connections shown in Table 6 in Section 3.2, we take 5 minus the mean score from the survey and add them to a type of waste when the CTQ is connected to that specific waste. For example, the waste type inventory is only connected to the CTQ concise dossier. The score for inventory will then be (5-2.96 = 2.04). The waste types with the highest scores are most present in the procedure. Table 15 shows the scores. We find that the waste type defects is most involved, while inventory and motion are the least. Knowing which waste types are most present will help us come up with useful and suitable improvements in the improve phase of our research, since the main goal should be to reduce these wastes.

Waste type	**Score**
Defects	14.53
Processing	10.16
Overproduction	8.77
Waiting	5.99
Transportation	4.54
Motion	2.19
Inventory	2.04

Table 15: Scores per waste type

3.5.2 Validity and limitations

As was shown in Table 6, the number of respondents is high and employees from all different functions have responded. This means that the results of the survey are a good representation of the experiences of the employees. By distinguishing the employees on their function, we are able to identify correlations between certain functions and their answers, should they exist. Furthermore, the large number of additional written explanations help with creating a better understanding of the results.

For the measurement of the performance of the CTQs, a 5-point Likert scale has been used. According to Cooper and Schindler (2014) a Likert scale is often more reliable than many other scales and the statements used should meet two criteria: The statements should be relevant to the attitude that is being studied and the statement should be able to reflect a favorable or unfavorable position on that attitude. The spread of answers given show that the statements reflect both favorable and unfavorable positions. Since the statements are derived from the CTQs that we have identified during interviews with stakeholders, we can also state that the statements are relevant to our topic of interest.

The danger with online surveys is that it is not possible to provide additional explanation may questions be unclear to respondents. By adding text blocks with explanations about the content, but also about the goal of the questions, we tried to make the questions as clear as possible. Furthermore, the open text options gave the respondents the opportunity to mention whether they misinterpreted a question.

3.6 Conclusion

In this chapter, we executed the measure phase of our research. We did this by first performing a literature search on how the performance of the RAMSHE LCM procedure could be best measured. We answered the following question:

"How can the performance of a procedure be measured in a lean perspective?"

We found that information waste is the main concept used to identify and measure process inefficiencies concerning processes like the RAMSHE LCM procedure. There are seven types of information waste: Overproduction, waiting, processing, defects, transport, inventory and motion. Case studies often also use value stream mapping in order to create an overview of the process and identify the waste. Furthermore, CTQs or Critical to Quality is often used to show the features that are critical the the customers' view of quality. Surveys can be used to measure the employee perspective on statements regarding the quality of the procedure.

We applied this knowledge by using the previously found CTQs and connecting them to the information waste types in order to already identify the possible waste in the procedure. We did not create a value stream map, since the procedure is not used consistently enough to be able to create a detailed map. The decision was made to measure the actual performance of the procedure by transforming the CTQs into statements. The results of the survey have been visualized and discussed in Section 3.4 and Section 3.5. These are used to answer the main subquestion of this chapter:

"What is the current performance of the procedure?"

The results of the survey confirm some of the initial problems found at the start of this research, namely that:

- The use rate is too low (30%)
- There is too little knowledge about the procedure (only 40.6% of the respondents that work in the relevant projects know about the procedure)
- 26.9% of the respondents that know the procedure do not or only partly understand its value. In other words, what the exact goal of the procedure is and why it is useful.

The following conclusions can be drawn about the CTQs:

- There is still a lot of room for improvement since 9 out of 15 of the statements about the performance of the CTQs are on average disagreed on.
- The additional explanations per function should be taken into account for the further analysis of the CTQs, since there is a high variety within the responses.
- All CTQs are considered important as they all scored sufficient on their perceived importance rating, however some are considered more important than others as the scores range from 6.17 to 8.50.

Furthermore, 76% of the respondents that know the procedure agree that clarifying the value of the procedure and making improvements based on the findings in this research will lead to a higher use rate. Of course, the respondents were not yet aware of the exact improvements, however this does show that most of the respondents are willing to use the procedure more often and are open to change.

Lastly, we determined which waste type is most present in the current procedure by creating scores based on the results of the survey and the earlier made connections between the CTQs and the types of information waste. We found that the waste type 'defects' is most present, followed by processing, overproduction, waiting, transportation, motion and lastly inventory. Defects, processing and overproduction all scored relatively high. During the improve phase a focus should therefore be put on decreasing the time and resources necessary to create excessive information and creating an unnecessary level of detail, decreasing the time and resources needed to transform information into the desired format and/or create workarounds when information is unavailable and decreasing time and resources necessary to verify and

correct provided information and/or resources to hunt down missing information.

In the next chapter the results of the CTQ scores, both the perceived performance and the perceived importance, will be further analyzed in order to determine the main bottlenecks and what causes them.

Chapter 4: Analyze

Now that the performance or 'as is' state of the procedure has been measured, this section will discuss the following subquestion of the research:

A1: *"What are the main bottlenecks within the procedure?"*

The question will be answered by addressing the following three questions:

- What bottlenecks can be identified?
- Which bottlenecks should be tackled first?
- What are the root causes of the selected bottlenecks?

The structure of this chapter will follow these three questions.

4.1 Possible bottlenecks

The possible bottlenecks are all the 15 CTQs that have been included in the survey. They can all be considered as possible bottlenecks since they all contribute to a type of information waste as was shown in Table 6. Furthermore, we found that all 15 CTQs are perceived as important to the successful performance of the procedure since we found in the results that they all scored higher than a 6 on a scale of 1 to 10. The next step is to analyze which bottlenecks need to be tackled first.

Figure 10: Importance v.s. Performance

4.2 Selection of bottlenecks

To be able to compare the performance of the CTQs with their perceived importance, Figure 10 was created. The figure shows how a CTQ has scored on both importance and performance and allows us to quickly see whether good performing CTQs are also seen as important. As mentioned earlier, these scores were given by the group of respondents that both know the procedure as well as use it or have used it before. When a CTQ is in the top right of the figure it scored very high on both performance and importance. For the improvement of the procedure, the most interesting CTQs are those that score low on performance, but high on importance. These would be located in the down right part of the figure. Since a performance score of below 3 means that on average employees do not agree on a CTQ, we select the CTQs that score below 3 on the performance and above 7 on the importance.

The selected CTQs (in order of lowest perceived performance to highest) are:

- Timely receival of needed information/input during the procedure;
- Conciseness of definitive RAMSHE dossier;
- Availability of specific RAM requirements at the start of the procedure;
- Availability of the needed information and input during the procedure;
- Knowledge about the use of the definitive dossier;
- Feasibility of the separate steps;
- Clearness about the value of the procedure.

The following two CTQs are added to the selection:

- Checking and monitoring of the execution;
- Knowledge among employees.

The checking and monitoring CTQ was not in the initial selection since the perceived performance was not below 3 (it was 3.04), but since it was very close, perceived as quite important (score of 7.6) and because there were two people who totally disagreed with the statement, we decided to still include this CTQ. We also included the CTQ about knowledge among employees, since this was experienced as by far the most important (a score of 8.48), but since the people who know the procedure are confident about their knowledge, it does not come out as a bad performing CTQ. However, from the other survey questions we know that the general knowledge about the procedure is very low. Therefore, the decision was made to include this CTQ. In short, 9 CTQs have been selected as the main focus points for improvement and will be further analyzed in this chapter.

4.3 Root cause analysis

There are different Lean methods that can be used during the analyze phase of the DMAIC cycle. For example, in a case study performed by Converso et al. (2025), an Ishawaka Diagram was created to identify root causes after which a "5 Whys" analysis was performed by their team in order to research the underlying causes.
Since the main bottlenecks have been identified, we only use the 5 Whys analysis to identify what the root causes of these bottlenecks are. Per CTQ, we shortly describe the root causes that can be found by the 5 Whys analysis. The reasoning is based on the conversations that were held with employees, the results and additional explanations of the survey and the documentation of ProRail. The analysis and outcomes are summarized in Figure 11.

4.3.1 Timely receival of input/information

This CTQ scored a 7.0 on perceived importance and 2.58 on performance, meaning that on average most of the employees disagree or are neutral about the fact that the required input and information is received on time during the procedure. When looking at the current procedure, there is no clear indication as to when exactly the information is needed, except for 'at the beginning of the next step'. Therefore, it is not clear when certain information is needed. Since the steps within the procedure follow the phases of the Kernproces, it gives some insight as to when the information might be needed, but this is only

clear if everyone is aware of the exact progress of the project and in which phase the project is and what the current status of the RAM analyses are. Since there are many different people and sometimes also engineering firms involved, it is easy to lose track of the progress. This can be caused by the fact that there is a lack of clear communication between employees on the expectations and progress.

4.3.2 Conciseness of definitive RAMSHE dossier

This CTQ scored a 7.04 on perceived importance and 2.96 on performance. This means that employees on average do not agree with the fact that the definitive dossier is concise. One of the respondents commented: "Only ask what will actually be used". We can therefore argue that the reason the dossier is not concise is that too much irrelevant information is asked. Therefore, too much information ends up in the dossier because it is not clear to the employees what should be in it exactly. This happens because it is not clearly indicated by AM what should actually be in the dossier. The main reason behind this is that it is currently not clear who from AM is actually using the dossiers and should therefore be responsible for indicated what should be in there.

4.3.3 Availability RAM requirements

Specific RAM requirements are often not available at the start of the procedure. This CTQ scored a 2.46 on the performance and a 7.12 on importance. According to the procedure, different RAM requirements (for example the desired number of trains and travelers of a new system) are provided by different departments (Asset Management, Capacity Management, external parties, etc.) at the very beginning of the procedure. Moreover, the Plan Developer should provide existing RAM data (gathered from the area teams) as input for the first step in the procedure.

The following was mentioned by a respondent about the availability of the RAM requirements: "The presence of the specific RAM requirements at the start of the procedure is only valuable if for every requirement there is an accepted (simple and efficient) method to prove that you meet the requirement." Another respondent (a Technical Project Leader) mentioned: "You often have to check for yourself which RAM goals should be pursued and how this is shown." Lastly, another respondent said the following: "The availability of specific RAM requirements does not apply to any project, because ProRail does not know how a project contributes to the performance of the whole country. There are national KPIs, but these cannot be translated into specific requirements. The goal is to create an overview of the performance without a clear requirement."

The opinions quite vary, but when looking at the procedure we can derive that a lack of RAM requirements at the start of the procedure is caused by the Plan Coordinator not providing them, which is caused by AM, CM or external parties like the customer not providing enough input on their desired RAMSHE goals.

4.3.4 Availability of needed information and input during procedure

This CTQ scored a 7.28 on importance and a 2.42 on performance. A few statements were made about the availability of needed information and input. These are: "Mostly, the information sources about current infrastructure are insufficient", "Everything depends on the availability of the existing dossier" and "I think everyone will answer this the same. There are no RAMS/LCM dossiers. But if we do not ask this within projects, they will never be there."

4.3.5 Knowledge use of the definitive dossier

This CTQ scored a 7.44 on importance and a 2.69 on performance. In the procedure, the content of the definitive dossier is described as the matters relevant to properly organizing and carrying out management and maintenance from the day of commissioning. Some comments were given by the respondents on their knowledge of how the definitive dossier is used by Asset Management. "I am not familiar with the use of the dossier after commissioning of the new infrastructure. I thought that it was mostly important during the early design phase." "In my experience, after delivering extensive reports and analyses, AM is only looking at the difference in the maintenance costs and the other matters disappear straight into the eternal archive. These other documents do not appear at a new project, even when asked." "I think RAMSHE LCM is useful for Asset Management. What they do with it is difficult to estimate for me."

When looking at these statements, we can conclude that it is not clearly communicated how the definitive dossier is actually used. Again the main reason behind this is that it is currently not clear who from AM should be responsible for this communication.

4.3.6 Feasibility separate steps

We found that the described steps within the procedure are not always executable since this CTQ scored a 2.65 on performance. Furthermore, it scored a 7.6 on importance. A respondent mentioned: "I think we should be critical at what steps are applied and whether the involved employees are open to this. SMART requirements have been a struggle for a long time. I would focus on the goals and principles and include this in the process." From this we can conclude that it is difficult to adhere to the SMART requirements that are asked in the procedure. Another respondent said: "AM can sometimes go overboard in asking about failure rates etc. while there is no new data on experience with new cases and we as ProRail have to take a risk. Not everything can be solved down to the decimal point." From these answers we can conclude that sometimes too specific results are asked when then there is not enough input to actually succeed in this.

4.3.7 Clearness about value of procedure

This CTQ scored a 7.98 on importance and a 2.81 on performance. Two reasons were given by respondents as to why the value of the procedure is not clear. There is a lot of overlap between different products that show the RAMSHE aspects as RAMSHE is mentioned in the business case, the MKBA and the FIS. Furthermore, during the design phase, the life cycle management is barely taken into account or used as input for decision making about designs. Another respondent later also mentioned that the procedure seems to bring together all separate procedures, but does this by asking even more products (the dossier). Another comment summarizes how the value could become more clear: "I think AM should put more effort into showing the users of the procedure what exactly is expected from them and in what cases the procedure actually provides added value."

4.3.8 Checking and monitoring

"It should be better monitored whether employees rightly deviate from the Kernproces and not just always continue a project without RAMS/LCM." According to the Kernproces and the procedure, the Projectmanager is accountable for checking whether all the necessary analyses are performed during the Kernproces, however we have also seen that 36% of the Projectmanagers who work in relevant projects do not even know the RAMSHE LCM procedure. Other respondents have given similar answers: "I do not understand that employees do not use the procedure and are allowed to continue within the Kernproces." "An automatic signal/reminder that your project should still execute the procedure helps as a trigger to actually deliver quality with regards to RAM. It is a part of the Kernproces, but nobody asks for it."

4.3.9 Knowledge among employees

There is too little knowledge among the employees about the existence of the procedure. The importance of knowledge about the procedure was rated with an average 8.48 on a scale of 1 to 10. A respondent mentioned: "I rated the knowledge among employees with a ten. This is of great importance, but currently not the case." That many employees do not know about the procedure is caused by the fact that they are not aware that they should even use it. This has two main reasons: Employees are not corrected when not using the procedure and the procedure is apparently not explained to new employees. These problems are caused by the fact that the execution of the procedure is not monitored and there being insufficient training about the application of RAMSHE LCM.

4.3.10 Root causes

In Figure 11, the complete analysis is summarized and we find that there are 13 root causes for the 9 selected problems. However, some root causes overlap with each other. For example, with the 5 Whys analysis we found that there are three root causes that come down to there being insufficient checking and monitoring of the execution of the procedure. Since this was a problem itself already, we can use the root cause of that problem to tackle all the problems in which insufficient checking and monitoring is the root cause. Furthermore, we see that both the problems of the definitive dossier not being concise and there

being insufficient knowledge on the use of the dossier both come down to the unclear communication from Asset Management. Lastly, we found that one of the root causes of the value not being clear is that there is not enough knowledge about when the procedure should be used, in other words, there is insufficient knowledge among the employees, which is also an identified problem. After eliminating this overlap we end up with the following actual root causes:

- No clear communication between employees on expectations and progress of the different steps of the procedure
- Lack of input from AM, CM or customer (for RAM requirements)
- No clear communication from AM about dossiers caused by lack of clarity about ownership of dossier
- Definitive RAM dossiers not stored
- Information sources with the standard expected RAM requirements have insufficiently been updated
- No data for new products due to lack of experience with the products
- Difference between RAMSHE procedure and other procedures (like the design regulations or PRC00055) should be clearer
- Projectmanagers are insufficiently trained on monitoring the execution of RAM
- Insufficient training about the overall application of RAMSHE LCM

Problem	1st Why	2nd Why	3rd Why	4th Why	5th Why
No timely receival of input	Not clear when input is needed	Hard to keep track of exact progress of procedure within project	Complex non-sequential procedure with many people involved	No clear communication between employees on expectations and progress	-
Definitive dossier not concise	Too much unnecessary information in dossier	Not clear to employees what should be in dossier	Not clearly indicated by AM what should be in dossier	No clear owner of dossier	-
RAM requirements not available	RAM requirements not clearly specified by Plan Coordinator	Lack of input from AM, CM or customer	-	-	-
Needed input not available	RAM dossier not available as input	RAM dossiers not asked as output during project	Insufficient checking and monitoring	-	-
		Definitive RAM dossiers not stored	-	-	-
	Information sources on current infra are insufficient	Not all information sources have been sufficiently updated	-	-	-
Insufficient knowledge on use of dossier	The complete content of the dossier is not visibly used	Not clearly communicated how dossier is used	No clear owner of dossier	-	-
Low feasibility of steps	Employees struggle with requirements	It is not possible to calculate everything to the dot	There is not always enough data to calculate the results that AM asks for	For some new products there is simply no experience data	-
Value of procedure unclear	Employees experience overlap with other procedures	RAMSHE is mentioned in other procedures as well, which make the procedure seem redundant	The difference between the RAMSHE procedure and the other procedures should be clearer	-	-
	Not often used in design phase (where it has most value)	Not enough knowledge about when it should be used	-	-	-
Insufficient checking and monitoring	It is too easy to go through the Kernproces without executing RAMS	RAMS is often not asked for	The Projectmanager is accountable, but has insufficient knowledge	Projectmanagers are insufficiently trained on monitoring the execution of RAM	-
Insufficient knowledge among employees	Employees are not aware that they should use a procedure	Employees do not get corrected when not using the procedure	The execution of the procedure is not monitored	-	-
		The procedure is not explained to new employees	Insufficient training about the application of RAMSHE LCM.	-	-

Figure 11: 5 Whys analysis table

4.4 Conclusion

The goal of this chapter was to answer the question: What are the main bottlenecks within the procedure?

First, we determined that all fifteen CTQs should be considered as possible bottlenecks, because they all contribute to a type of information waste when performing bad. Furthermore, from the survey we found that all fifteen CTQs are perceived as important to the successful performance of the procedure since they all scored higher than a 6 (out of 10) on perceived importance.

The fifteen CTQs have been further analyzed by comparing the average scores of importance and performance. For the selection of the CTQs, we looked at the CTQs that scored below 3 on the performance and above 7 on the importance. Seven CTQs were found by using these constraints. These are: timely receival of input, conciseness of the dossier, availability of RAM requirements at the start of the procedure, availability of information and input during entire procedure, knowledge about the use of the dossier, feasibility of the separate steps and clearness about the value of the procedure. An additional two CTQs were added to the list of selected CTQs since they were considered too important to be left out as explained more clearly in Section 4.2. These are: Checking and monitoring of the execution and knowledge among employees. In short, nine CTQs have been selected for further analysis.

The nine selected CTQs have been analyzed by performing a 5 Whys analysis in order to find the root causes leading to the insufficient performance of the CTQs. The goal of the 5 Whys analysis is to ask the question, why?, until you find the root cause. The root cause is usually found within 5 times why.
Thirteen root causes have been found, which could be narrowed down to nine after eliminating the overlap. The final root causes are:

- No clear communication between employees on expectations and progress of the different steps of the procedure
- Lack of input from AM, CM or customer (for RAM requirements)
- No clear communication from AM about dossiers caused by lack of clarity about ownership
- Definitive RAM dossiers not stored
- Information sources with the standard expected RAM requirements have insufficiently been updated
- No data for new products due to lack of experience
- Difference between RAMSHE procedure and other procedures (like the design regulations or PRC00055) should be clearer
- Projectmanagers are insufficiently trained on monitoring the execution of RAM
- Insufficient training about the application of RAMSHE LCM

In the next chapter, we look at what improvements can be made to tackle the root causes.

Chapter 5: Improve + Control

With the identification of the root causes, the next phase of the research can be entered. As discussed in the research approach in Section 1.3, the following question is central to this chapter:

"What methods can be used to address the bottlenecks?"

In Section 5.1 we introduce the proposed improvements. In Section 5.2 we discuss the impact that the improvements have on the types of information waste that are identified in the procedure. In Section 5.3 we explain the impact/effort matrix and place our proposed improvements in it. Lastly, in Section 5.4 our implementation advice is given, supported with a flowchart.

5.1 Improvements

To come up with possible improvements, multiple factors were taken into account. Naturally, the identified root causes were used as the main source of inspiration, but we also factored in what we have learned during the semi-structured interviews with stakeholders as well as what we have learned from the, sometimes very elaborate, additional comments given in the survey. An initial list of possible improvements was created and discussed with a department manager of AM RailTechniek to ensure that the improvements are feasible and therefore can actually be implemented at ProRail. The final list of improvements is the following:

Ownership of dossier

In order to tackle the issues of it not being clear what should be in the definitive dossier and how it is used, the communication from AM should be improved. The first step should be to make it more clear who from AM is responsible for the use of the definitive dossier.
In the final step of the procedure it states that AM will focus on the management, maintenance and monitoring of the performance of the new infra and the RASCI mentions that the area manager of AM Daily Operation is responsible for this. However, after contacting an area manager of Daily Operation, we found out that he was not aware of this. We got referred to an operational manager, but they also seemed to not know about RAMSHE.
It should therefore be made clear who is actually responsible for owning and using the dossier. If it turns out there is actually no one currently using the dossiers, it should seriously be reflected on whether it then makes sense to keep on creating the dossiers or if it might be better to incorporate RAMSHE LCM completely in the other procedures. We will elaborate more on this at a later point in this chapter at Section 5.4.

Communication from AM

Once it becomes clear who is actually responsible for the use of the RAMSHE LCM dossier, they should critically reflect on what they actually use from the definitive dossier and whether everything they currently ask for is actually necessary. There exists a template for making a RAMSHE LCM dossier. This template has been last updated in May 2020. After critically reflecting which of the content is actually used and which not, this template should be updated.

RAMSHE LCM environment

This improvement aims to tackle the insufficient communication between employees on the expectations of RAMSHE LCM within their project and the actual progress. Since many people are involved, important information can get lost during the process. For example, at the start of the procedure a plan is made about which analyses should be performed, but later on it can get outsourced to an engineering firm that performs all possible analyses, which is a waste of time and money. To prevent this, there should be one place in which all the progress of the RAMSHE procedure is clearly shown and supplemented with important decisions and other informative documents. It could for example enable employees to mark which analyses should be performed according to the created RAM plan, in what phase the procedure currently is in and who are responsible. This way, all involved players are aware of the progress and important decisions that are made during the procedure.

Currently, ProRail already uses a shared online environment for their projects. Every project has its own Sharepoint site with a standard layout that includes the following:

- An image of the Kernproces;
- The current phase of the Kernproces that the project is in;
- An overview of all project staff and their role within the project;
- Folders for every subphase of the Kernproces that should be filled with relevant documents of that phase during the execution of the project.

When looking through several existing project Sharepoints, RAMSHE LCM is not found. Since the procedure is non-sequential (meaning that certain steps can be performed multiple times during multiple phases of the Kernproces), we propose to create a separate standard folder named RAMSHE LCM in which all documents regarding the procedure can be stored. This way, all relevant information regarding RAMSHE LCM can be easily found and does not get lost in the earlier phases of the Kernproces. Furthermore, the presence of this folder will also serve as a reminder for people to include RAMSHE LCM in their project or include a clear explanation as to why it is not needed for their project. This also makes the monitoring of the execution of the procedure easier.

Storing existing dossiers

The definitive RAMSHE dossiers should from now on always be stored in an easily accessible online space so that they can be used as input for new projects. This should be added to the final step of the procedure so that it is clear to everyone who is responsible for storing the dossiers and where they can be found. The dossiers should be classified based on location, since they contain location specific information that is useful as input for a new project on that location.

Reducing overlap in procedures

If the RAMSHE LCM procedure asks for certain results or analyses, this should not also be asked in another procedure. In order to make sure that the procedure itself actually adds sufficient value, the overlap with other procedures should be reduced. To do this the following steps should be executed:

- Determine in which procedures there might be overlap;
- Closely compare the RAMSHE LCM procedure to the found procedures;
- When overlap is found, make a decision on which procedure the task belongs to and remove the task from the other procedure.

During our research, certain examples of overlap were given by employees, but due to the time constraint of this research, we were not able to analyze the other procedures and make more specific recommendations about the overlap.

Staff training

To increase the awareness of the procedure and knowledge on how to properly execute it, there should be invested in better training of employees. Every new employee should receive an introduction about RAMSHE LCM and its importance.
ProRail has its own training platform called ProLeren. For every function there is a set of mandatory trainings, readings and exercises that have to be followed by the employee. Currently, there is nothing mandatory on the topic of RAMSHE LCM. Therefore, an introductory training about how to apply RAMSHE LCM in projects should be added to the mandatory trainings for new employees. This way, the knowledge about the procedure will drastically improve. A second, more elaborate training should be created for employees that work in large projects in which new infra is created, since these are the projects in which RAMSHE LCM has the most impact.

Standard monitoring

The execution of the procedure and the creation of the associated RAMSHE LCM dossiers should be monitored. The Projectmanager is currently accountable for the execution of RAMSHE LCM within a

project, but does not have sufficient knowledge, since we found that 36% of the Projectmanagers that work in the relevant projects know the procedure. The previously mentioned staff training will help increase their knowledge about the procedure, but the Projectmanagers should also receive more specific information so that they are actually able to monitor the execution of the procedure.
Another option would be to create more RAMSHE LCM specialists who would take over the responsibility of the Projectmanager with regards to monitoring the execution of the procedure. The downside is that this will get even more people involved and it will take time for the RAMSHE LCM specialists to first get briefed on the entire project before being able to assess how well RAMSHE LCM is implemented. Taking into account that ProRail is not looking to expand their staff, we do not recommend this.

5.2 Impact on waste

Next to ensuring that the proposed improvements solve the root causes leading to the bad performance of the procedure, the impact of the improvements on the existing waste should be determined. The reduction of waste is a key part in process improvement using a lean perspective and the more waste reduction is enabled by the proposed improvements the better the total improvement will be. Table 16 shows which waste types the improvements will reduce.

Improvement	**Waste type**	**Description**
Ownership of dossier	Inventory	Until it is clear who owns and uses the information within the final dossiers, redundant information is maintained, since it is not clear whether the dossiers are actually used.
Communication from AM	Overproduction	When it is more clear who owns and uses the dossiers, they can specify what they exactly want in it. This prevents unnecessary information being created that is not actually used.
RAMSHE LCM environment	Overproduction	When everything is in one place, it becomes less likely that double work is performed.
	Waiting	There is less waiting for input to be shared, since all RAMSHE LCM related documents will be uploaded in the same place.
	Defects	Less time and resources necessary to hunt down missing information, since everything is stored in the same place.
	Transport	Less time and resources necessary to extract information from multiple sources.
	Motion	Less time spent on moving information caused by lack of real-time access.
Storing existing dossiers	Defects	Less time spent on verifying and correcting information and hunting down missing information.
Reducing overlap	Overproduction	Ensures that the exact same things aren't done multiple times.
Staff training	Waiting	Less waiting when all employees are aware how to execute the procedure.
	Processing	Less time and resources necessary to transform information into the right format, when employees know what the format of the output should be.
	Defects	Less time spent on correcting provided information from employees in previous steps.
Standard monitoring	Defects	Less time spent on hunting down missing information, since it is monitored that all necessary information is created.

Improvement	Waste type	Description

Table 16: Impact of improvements on information waste

From the table we can see that especially the waste types 'defects' and 'overproduction' will be reduced. According to the scores of Table 15 in Section 3.5, these were in the top three most present wastes in the current procedure. We can therefore conclude that the proposed improvements will have an actual impact on the performance of the procedure as they tackle the most present waste types.

5.3 Impact/effort matrix

To determine the order in which the improvements should be implemented, an impact-effort matrix is used. Examples of its application can be found in among others papers of Kowalik (2018) and Ozola and Lapina (2023). They both use the impact-effort matrix to determine which solutions should be implemented first. Scores can be given to the solutions in order to place them in the matrix. Intuitively, the solutions that require the least effort, but have the most impact should be implemented first.

For all earlier mentioned proposed solutions, the impact and effort are estimated and rated with a score between 1 and 5. For the impact, we take into account how many of the root causes the improvement tackles as well as how big these root causes are. For the effort, we take into account how long it would probably take to implement and how many people are needed. The scores are shown in Table 17.

Improvements	Impact	Effort
Ownership of dossier (1)	5	2
Communication from AM (2)	4	3
RAMSHE LCM environment (3)	4	2
Storing existing dossiers (4)	3	2
Reducing overlap (5)	3	4
Staff training (6)	5	4
Standard monitoring (7)	4	3

Table 17: Overview of improvements with impact and effort scores

The improvements have been placed into an impact-effort matrix based on their given scores. The matrix is shown in Figure 12. Improvement 2 and 7 both scored a 4 on impact, but improvement 2 has been put above improvement 7, since we estimate it to have more impact out of the two improvements.

We see that the proposed improvements all fall under the top two quadrants of the matrix, which are the 'quick wins' and the 'major projects'. In the next subsection, we elaborate on how this is translated into the implementation advice.

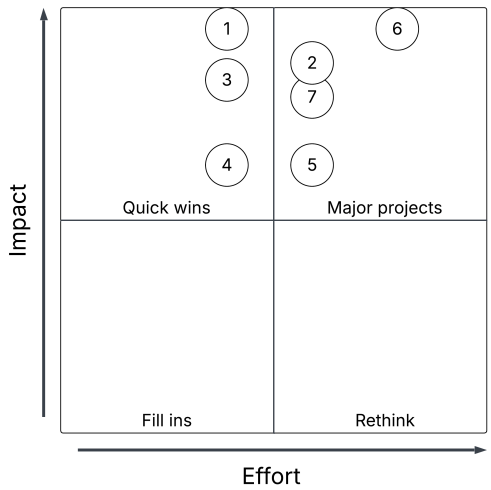


Figure 12: Impact-effort matrix

5.4 Implementation advice

The top left quadrant of the impact-effort matrix, shows the improvements that require the least effort, but have the highest impact. We call them 'quick wins'. These should be implemented first. In the top right quadrant we find the improvements that require more effort, but also have a high impact. We call these 'major projects', because they will need more time and resources to implement, but are valuable as they also have a high impact.

Following the logic of the impact-effort matrix, it makes sense to first implement the 'quick wins' from order of highest impact to lowest (1-3-4), before implementing the 'major projects'. For these improvements we would implement the improvements with the least effort and the highest impact first, starting with the least effort (2-7-5-6). These orders are used as a basis to create the final implementation advice which is shown in the flowchart in Figure 13.

The flowchart can be read as follows: When starting the improvement process, the ownership of the definitive RAMSHE LCM dossier should first be identified. In Section 5.1, we already shortly mentioned that if it turns out there is actually no one currently using the dossiers, it should seriously be reflected on whether it makes sense to keep on creating the dossiers or whether it might be better to incorporate RAMSHE LCM completely in the other procedures. This decision process is also shown in the flowchart. When no actual owner can be identified, it could be said that the dossier is redundant, since it is not used by anyone. It should be well reflected whether a new owner should be selected and whether the dossier will then actually be used. If the decision is made to not select a new owner, the procedure should be incorporated into existing procedures. However, when the owner and user of the definitive dossier is actually identified, the other improvements should be implemented, starting with the quick wins.
We deviated slightly from the order of improvements as found in the impact-effort matrix, since it makes more sense to first improve the procedure itself before investing in training of staff and educating the Projectmanagers on how to monitor the execution of the procedure.

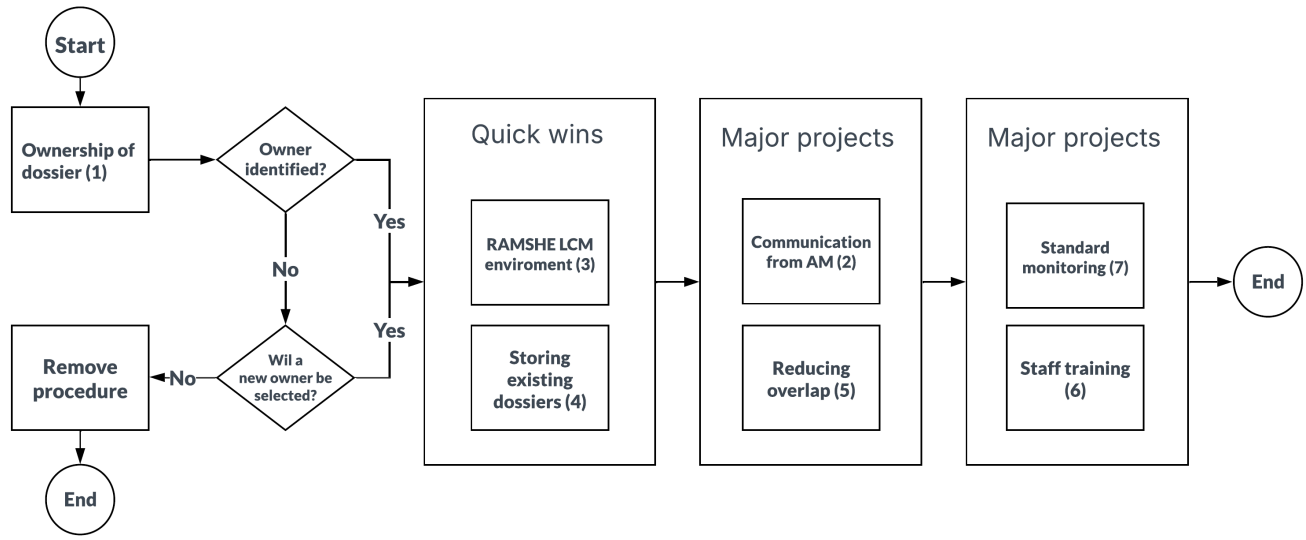


Figure 13: Flowchart implementation advice

Within ProRail there is a team that supports owners of changes in processes or ways of working and advises them during all phases of an implementation trajectory. The team is called IMPROVE and exists out of a variety of employees from different departments. Every quartile IMPROVE arranges a broadcast for all involved staff in which the owners of the change can present and explain the changes. IMPROVE should be contacted to help with the further and more detailed planning of the separate improvements.

5.4.1 Sustainable improvement

An important part of the Control phase of the DMAIC cycle is to ensure that the proposed solutions are sustainable. The PDCA Cycle is a lean approach that enables continuous improvement (Bertagnolli,

2022). It stands for 'plan, do, check, act' and it ensures consistent and sustainable implementation of topics. PDCA is already often used within ProRail, so it can serve as a suitable technique to ensure a sustainable improvement in this case as well.
For all proposed improvements a more detailed plan should be made (Plan), which should then be executed (Do) after which it should be checked on whether it does what it needs to do (Check). If it turns out that the desired effect is not reached, for example if instructing the Projectmanagers still does not lead to a better monitoring of the procedure, adjustments should be made in order to ensure that it does reach its desired goal (Act).
By continuing to perform this cycle, sustainable improvement is ensured. Even when the use rate of the procedure has drastically improved, it is still important to keep in close contact with the employees on their experiences with the procedure and keep improving where possible.

5.5 Conclusion

In this chapter several improvements have been proposed based on the root causes that have been identified in Chapter 4. These are:

- Clarifying the ownership of the final RAMSHE LCM dossier
- Creating a RAMSHE LCM environment in the sharepoint page used for projects
- Storing the existing final RAMSHE LCM dossier consistently
- Arranging better and more clear communication from Asset Management
- Reducing the overlap between PRC00290 and other procedures
- Ensuring standard monitoring of the execution of the procedure
- Training staff on how to execute PRC00290

The impact of the proposed improvements on the different types of information waste have been described and we found that the waste types 'overproduction' and 'defects' will mostly be reduced by these improvements. During the measure phase of the research we found that these were also in the top three of most present waste types in the procedure. We therefore conclude that the proposed improvements will have a positive impact on the performance of the procedure.

The proposed improvements have been rated based on impact and effort and visualized in the impact-effort matrix in order to determine the order in which the improvements should be implemented. A flowchart has been created to visualize the implementation advice. To enable sustainable improvement, we suggested to use PDCA (Plan Do Check Act) cycles as well as ProRail's own IMPROVE program which supports successful implementation of change and improvements.

Chapter 6: Conclusion and further research

In this chapter we provide the conclusion of our research and discuss what further research is recommended.

6.1 Conclusion

We summarize the findings of each of the separate research questions and finally answer the main research question.

D1: How can the current RAMSHE LCM procedure be described?

This question is answered in the define phase of our research. Although multiple documents have been found that show different ways of how RAMSHE LCM should be incorporated into railway infrastructure projects, we found that PRC00290.V002 is the actual procedure that is meant when talking about the RAMSHE LCM procedure. This procedure is a non-sequential procedure which is designed based on the, within ProRail well known, Kernproces Projecten. It consists of 14 different steps that are all explained within the procedure and supplemented with the necessary input, expected output, and related RASCI table.

D2: Who are the stakeholders and what is their role in the procedure?

This question is answered in the second part of the define phase by performing a short stakeholder analysis. The RASCI tables and explanations from the procedure have been used to identify the stakeholders and their roles within the procedure. A selection of 8 different stakeholders have been interviewed to inform about their knowledge, the correctness of their described roles and their actual involvement with the procedure. The stakeholders that were interviewed are: Plan Coordinator, Plan Developer, Technical Project Leader, Project Manager, Constructoin Manager, Area manager CM, Area manager AO&I and Area manager DO. Based on the interviews, we defined the stakes of the stakeholders, interpreted as level of interest. We found that the Technical Project Leader and the Plan Developer have the highest stakes, followed by the Plan Coordinator, Project Manager and Construction Manager. The lowest stakes belong to the Area managers of CM, AO&I and DO.

D3: Which outcomes and characteristics of the procedure are valued by the stakeholders?

This question completes the define phase of the research. During the interviews with the stakeholders, two important questions for the continuation of the research were answered. Firstly, the purpose of the procedure from the perspective of the stakeholders has been identified and summarized as the following: "The procedure should timely prove the required reliability, availability and maintainability of a new system in order to make the right decision ensuring low life cycle costs while adhering to the vision and regulations of ProRail." Furthermore, the term 'Critical to Quality' has been introduced as a way to indicate the desired characteristics of the procedure. Fifteen different CTQs have been identified and were ranked based on how often they were mentioned during the interviews. The fact that employees should have sufficient knowledge about the procedure was mentioned most often.

M1: How can the performance of a procedure be measured in a lean perspective?

This question forms the base of the measurement performed in Chapter 3. We found that lean information management can be used to identify improvement opportunities. Seven types of information waste are defined: Overproduction, waiting, processing, defects, transport, inventory and motion. Next to information waste, CTQs or Critical to Quality can be used to identify the desired quality of the procedure. The CTQs therefore sketch an image of what the procedure would look like in a perfect world, which can be seen as the 'to be' state of the procedure. A case study has used surveys as a way to measure process performance. Other case studies have used Value Stream Mapping as a way to create an overview of the process 'as is', but since the RAMSHE LCM procedure has such a low use rate and not used in a consistent manner, we did not have enough information to create a Value Stream Map.

We applied the literature by using our previously identified CTQs and identifying which waste types they could incur when performing bad. This gave us an indication of the possible waste within the procedure. A survey has been created to measure the actual performance of the procedure. This is done

by translating the CTQs into statements and asking the respondents to what extent they agree with the statements with a 5 point Likert scale. The survey has been sent to a total of 486 employees consisting of Technical Project Leaders, Plan Coordinators, Plan developers, Projectmanagers and Construction Managers.

M2: What is the current performance of the procedure?

This question concludes the measure phase of the research and is answered by discussing the results of the survey. With the results of 109 respondents we have found that 40.6% of the employees that work in relevant projects know the procedure and that the use rate of the procedure among those employees is just 30%. 26.9% of the respondents that know the procedure do not or only partly understand its value. There is therefore still a large part that does not understand what the exact goal of the procedure is and why it is useful. Furthermore, the performance of the procedure has been identified by measuring the perceived performance of the separate CTQs from the perspective of the employees. The CTQs have been transformed into statements on which the employees could indicate their level of agreement. Nine out of the fifteen CTQ statements were on average disagreed on, meaning that there is still a lot of room for improvement. To measure which CTQs are considered most important by the employees, the perceived importance of the separate CTQs has also been measured. All CTQs were considered to be important as the scores range from 6.17 to 8.50 (out of 10).

By combining the performance scores of the CTQs and the types of information waste that were connected to the CTQs, scores were given to the types of waste to give an estimation of which waste types were most present in the current procedure. We found that defects was most present followed by processing, overproduction, waiting, transportation, motion and lastly inventory.

A1: What are the main bottlenecks within the procedure?

By analyzing both the perceived importance and performance of the fifteen CTQs that were included in the survey, we created a selection of the bottlenecks that were most critical. Seven CTQs scored below a three on performance, meaning that they were on average disagreed on, while scoring higher than a 7 on importance. These are: Timely receival of input during procedure, conciseness of definitive RAMSHE dossier, availability of RAM requirements at start of procedure, availability of needed input during the procedure, knowledge about use of definitive dossier, feasibility of separate steps and clearness about the value of the procedure. We added the CTQs 'checking and monitoring of execution' and 'knowledge among employees' to our selection of critical CTQs, since the CTQ of checking and monitoring only just fell out of the requirements with a performance score of 3.04 and the CTQ of knowledge scored very high on performance, but was only answered by the employees that had sufficient knowledge while there are still many employees who do not have any knowledge about the procedure.

To identify the root causes of the bad performing CTQs we performed a 5 Whys analysis on the nine selected CTQs. The following root causes were identified:

- No clear communication between employees on expectations and progress of the different steps of the procedure
- Lack of input from AM, CM or customer (for RAM requirements)
- No clear communication from AM about dossiers caused by lack of clarity about ownership
- Definitive RAM dossiers not stored
- Information sources with the standard expected RAM requirements have insufficiently been updated
- No data for new products due to lack of experience
- Difference between RAMSHE procedure and other procedures (like the design regulations or PRC00055) should be clearer
- Projectmanagers are insufficiently trained on monitoring the execution of RAM
- Insufficient training about the application of RAMSHE LCM

I-C1: What methods can be used to address the bottlenecks?

This question covers both the improve and control phase of our research. By combining the knowledge gathered from the root cause analysis with all the previous research and held conversations with employees, different improvements were created. The improvements have been discussed with the department manager AM RailTechniek to ensure their quality and feasibility, which has resulted in a list of seven improvements. These are:

- Clarifying the ownership of the definitive dossier
- Improving the communication from AM about their expectations
- Creating a RAMSHE LCM online environment
- Storing the existing dossiers
- Reducing the overlap with other procedures
- Implementing mandatory staff trainings
- Ensuring the standard monitoring of the execution of the procedure

We analyzed which waste types the improvements would reduce and we found that the improvements will lead to a reduction of all seven waste types, but mostly the reduction of the waste types defects and overproduction. Since these were one of the most found waste types in the current procedure, we can use this to conclude that the proposed improvements will have an actual impact.
The improvements have been rated based on their expected impact and effort and visualized in an impact-effort matrix which has served as a guideline for the implementation advice. As a result, a flowchart has been created which visualizes the implementation advice. Finally, we recommend ProRail to use the IMPROVE team to help with a smooth implementation and to use PDCA cycles to ensure sustainable improvement.

Main research question: How can the use rate of the RAMSHE LCM procedure be increased while identifying the added value and eliminating waste?

The added value of the procedure has been identified and validated multiple times during this research by including and comparing the value as stated in the documents, as experienced by the interviewed stakeholders and as experienced by the respondents of the survey. The value of the procedure is that it enables ProRail to timely prove the required reliability, availability and maintainability of a new system in order to make the right decision ensuring low life cycle costs while adhering to the vision and regulations of ProRail.

Everything that does not add something to the identified value can be seen as waste. In the current procedure all seven types of information waste can be found. By implementing the proposed improvements the amount of waste decreases.

During our problem identification in Section 1.2 we found that there are four factors directly leading to a low use rate. These are a low ease of use, the procedure being unknown to employees, the value of the activities not being clear and a high perceived effort. The proposed improvement of reducing the overlap between the procedures will help with tackling the low ease of use. Arranging better and more clear communication from Asset Management will help with tackling the high perceived effort and making the value of the activities more clear. The online RAMSHE LCM environment will also contribute tackling the low ease of use. Training staff on how to execute PRC00290 will help with increasing the knowledge of the employees. We see that all four factors leading to a low use rate are tackled by the proposed solutions. Furthermore, ensuring standard monitoring of the execution will ensure that it will always be executed when necessary. We can therefore conclude that the use rate will go up once the proposed improvements are implemented.

6.2 Further research and limitations

During this research it became clear that there is plenty of literature on the application of Lean Six Sigma within the manufacturing industry, but much less in other environments. With complex procedures, like the RAMSHE LCM procedure, we found that especially the measure phase can be challenging to execute. Further research into strategies that can be used to make the performance of a complex process or procedure measurable would therefore be valuable. In this research, we selected fifteen CTQs as metrics, but there might still be more relevant performance metrics that could be used to paint an even better picture of the actual performance. A more extensive research on performance metrics could clarify which metrics could be best used for similar researches in the future.

For the improvements, we made the decision to focus on 9 of the 15 CTQs that were incorporated in the survey. These were selected by looking at the CTQs with a performance score below 3 and an importance score above 7. There are of course also different ways to select the CTQs. A selection of different CTQs could have led to different improvements, so further research could also incorporate the CTQs that were now not taken into account.

Several recommendations have already been given for the implementation of the improvements, however, much of the success of the implementation will lie in the hands of its users and whether the changes will be accepted. As was mentioned earlier PDCA cycles can be created to ensure proper implementation of the proposed improvements. ProRail would therefore have to look into the proposed improvements and during the planning phase also take into account how employees will react to the changes.

Lastly, this research has focused on the improvement of the RAMSHE LCM procedure itself, but once the improvements have been implemented and the use rate of the procedure has improved, it would be valuable to look into how the RAM performance of the new infra can best be monitored. Once the use rate of the procedure is up, it opens up many opportunities for gathering more relevant data and making better decisions using that data.

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A Problem context survey results

On the following pages, the results of the survey used for the problem analysis can be found.

The research population exists out of 21 Rail System Engineers (Technisch Projectleiders in Dutch). The survey has been spread through a QR code on a presentation slide of a short presentation of the research assignment during a monthly meeting with the whole department of RailTechniek.

Q3 - Kent u de RAMSHE LCM procedure? (Heeft u ervan gehoord?)

17 4

Q4 - Gebruikt u de RAMSHE LCM procedure weleens? - Selected Choice

6 11

Q4_2_TEXT - Nee, want ... - tekst

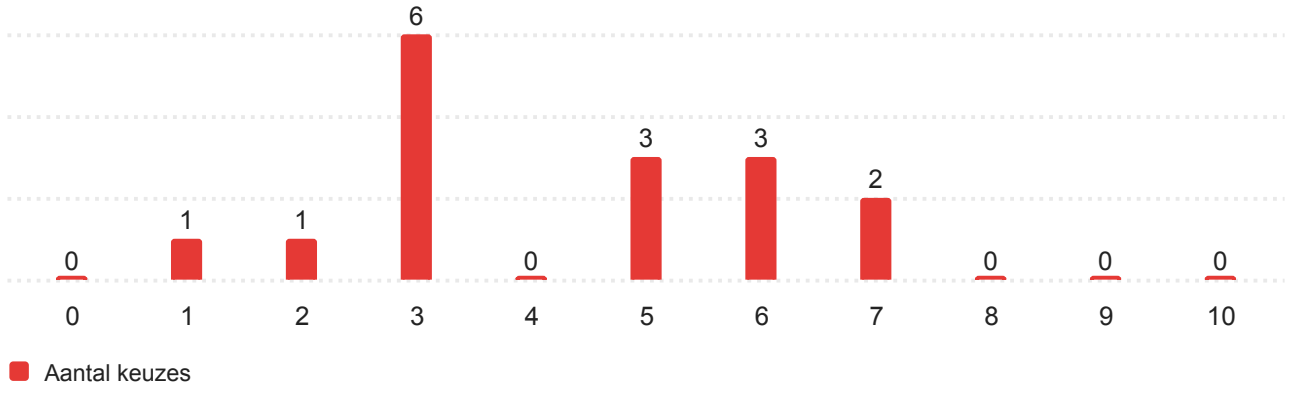
Nee, want ... - tekst
Ik doe dit werk pas een jaar en heb dit nog niet aan de hand gehad.
In mijn vorige rol gebruikte ik de LCM tooling. Als TPL werk ik alleen vorm aan de opzet en invulling voor de te beschouwen alternatieven. Het IB werkt deze dan uit.
Weet hem nog niet goed toe te passen
Omslachtig proces.
- De procedure is te abstract; - Gebrek aan kennis en kunde binnen en rondom het projectteam en (interne) opdrachtgever.
In samenspraak met de vakspecialist in de Regio gebruikt voor een groot project. Waarin gezamenlijk de getallen worden ingevoerd. Dus het is deels en niet zelfstandig
Op lang lopende projecten (+10) jaar doen we dit wel een keer, maar heel heel weinig.
Valt in de projecten

Ik heb in praktijk eigenlijk nog nooit mee gemaakt dit dit tot andere oplossingen en/of keuzen heeft geleid.

bij mijn projecten is dat al eens gedaan of het is niet relevant voor mijn project.

Onderhoudbaarheid wordt vaak impliciet meegenomen in ontwerpkeuzes in mijn projecten. Maar naar de procedure wordt zelden tot nooit gevraagd, en zodoende (helaas) ook niet opgesteld.

Q6 - Op een schaal van 0 tot 10, hoe duidelijk is het wanneer de RAMSHE LCM procedure gebruikt dient te worden?



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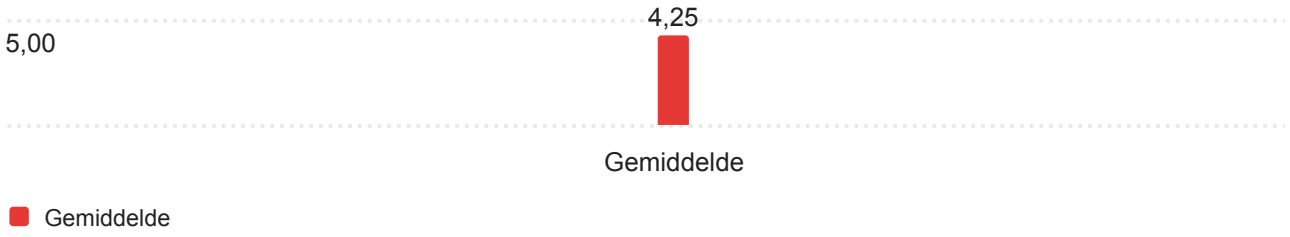
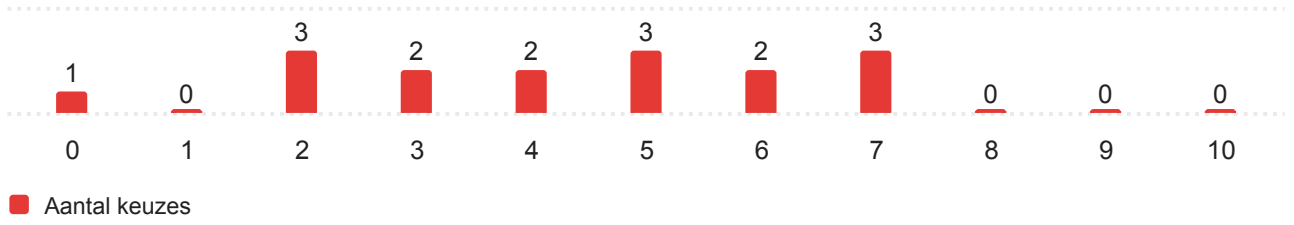
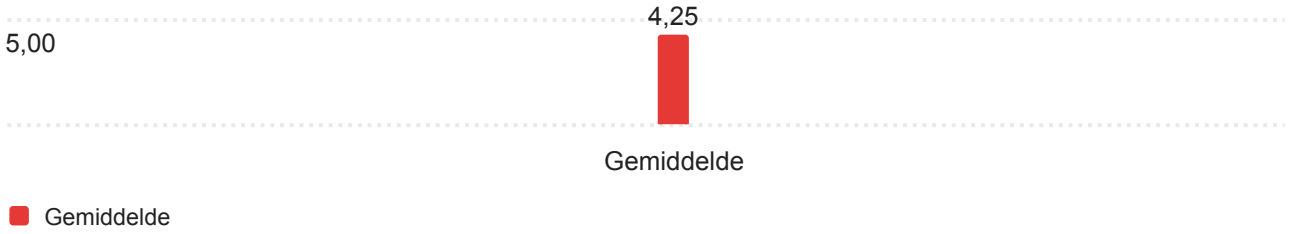


Q7 - Op een schaal van 0 tot 10, hoe tevreden bent u over de werking van de RAMSHE LCM procedure?



Q7 - Op een schaal van 0 tot 10, hoe tevreden bent u over de werking van de RAMSHE LCM procedure?



Q8 - Is het duidelijk wat de waarde van de RAMSHE LCM procedure is? - Selected Choice

Q8_1_TEXT - Ja, want - tekst

Ja, want - tekst

bij complexe projecten is het belangrijk alles gestructureerd in kaart te hebben.

Duidelijk wat de prestaties zijn en of bijzonderheden die een OCA zou moeten weten. Zoals de RAMSHE dossier nu worden opgesteld schiet het zijn doel voorbij. Te groot en te veel randzaken die niet bijdragen. Daarnaast worden de dossier niet opgeslagen waardoor voor projecten onbekend is wat de huidige situatie is

Q8_2_TEXT - Deels, want - tekst

Deels, want - tekst

eigenlijk wil ze min mogelijk onderhoudt

In veel OVS'n staan RAM's getallen. DE meeste OVS'n zijn alleen "verouderd" waardoor ook de RAM's parameers wijzigen. Of de alternatieve produkten ook aan deze RAM's parameters voldoende is te bezien. Als TPL is hier geen sturing in mogelijk.

Beheersbaar en onderhoudbaar ontwerp maken

Ten behoeve van het onderbouwen van een aantal aspecten is er onduidelijk wat er wordt verwacht. Voor wat betreft de M- zijn er geen kengetallen voor wat betreft het onderhoud en de kosten daarvan bekend of beschikbaar.

Onze assets moeten voldoen aan de eisen en regelgeving t.a.v. RAMSHE LCM.

In RAMS LCM zit niet alles wat je dient af te wegen.
Hoe zit het met CO2
Kosten van eerder vervangen en wat hogere kans op storingen kun je ook niet opnemen

Een variant die minder kost in aanleg maar meer kost in de beheerfase is in de praktijk 'verboden', ook als deze vanuit RAMS gunstiger is.

Het meenemen van RAMSHE aspecten is heel belangrijk bij het opstellen van een goed ontwerp en kan helpen om daarin de juiste keuzes te maken. Maar hoe dit momenteel geborgd is en/of gebruikt wordt binnen ProRail is mij (nog) niet helder.

Q8_3_TEXT - Nee, want - tekst

Nee, want - tekst

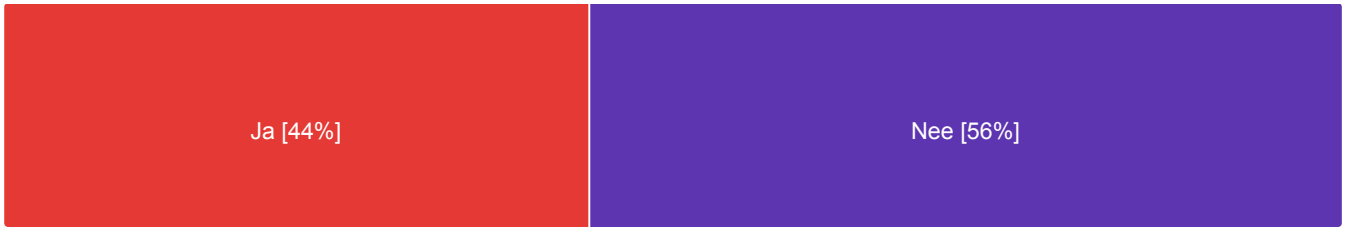
Zeker toegevoegde waarde, maar rrvaring is dat er geen ProRail functionaris is die product toetst en in ontvangst neemt.
Zonder van al het werk

Het blijft heel vaak hangen in algemeenheden en open deuren.

Het LSM deel ken ik wel heel goed maar het RAMSHE aspect in nauwlijkt te vinden of bijna nooit nodig.

Ik hoor te weinig uit projecten of het toegepast wordt en wat de ervaringen zijn

Q9 - Ervaart u dat er soms overlap zit in de verschillende stappen van de procedure met mogelijk (onnodig) dubbel werk als gevolg?



7 9

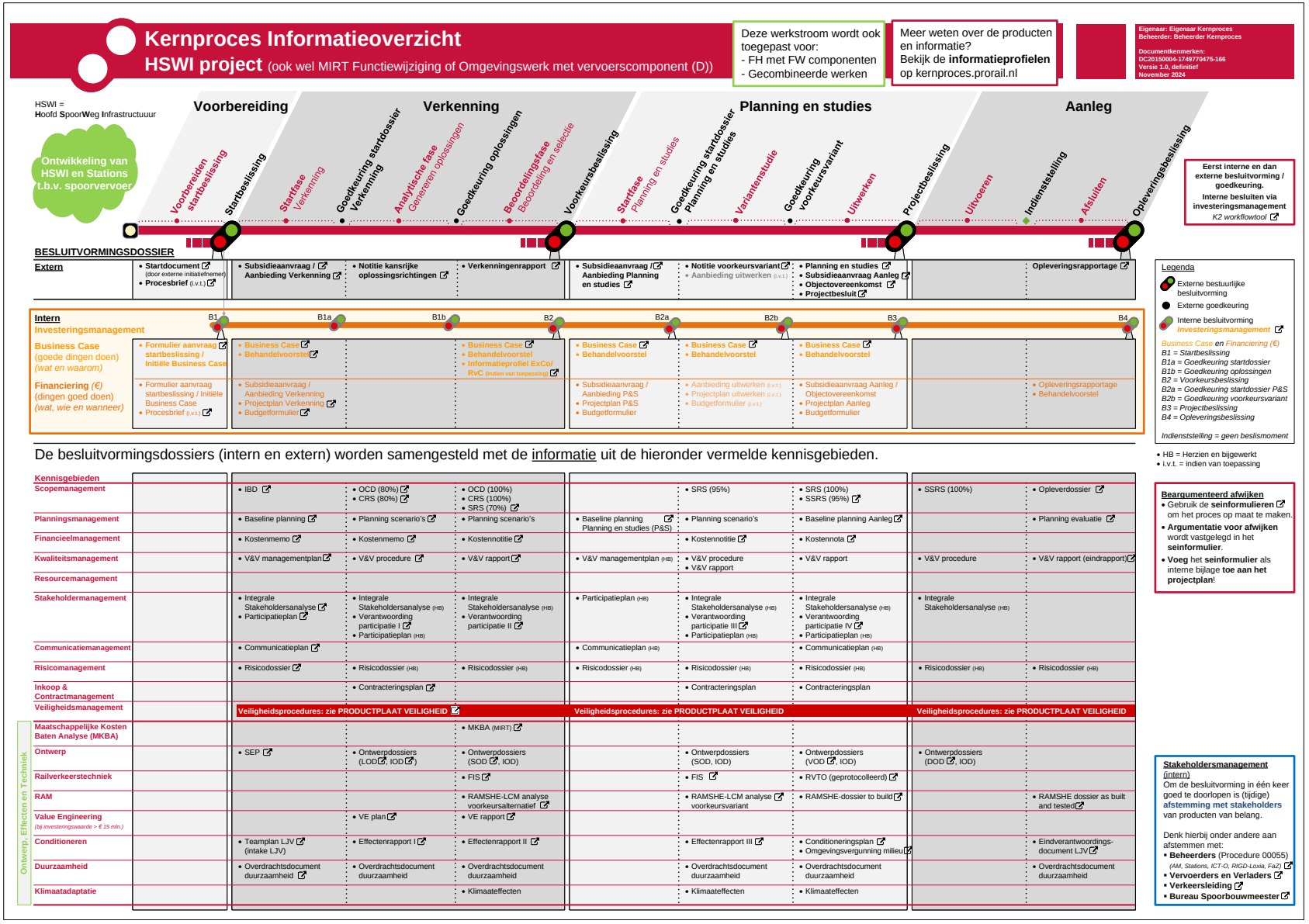
Q12 - Wilt u nog iets extra's toevoegen over uw ervaringen met de RAMSHE LCM procedure of wilt u nog iets anders kwijt?

Wilt u nog iets extra's toevoegen over uw ervaringen met de RAMSHE LCM procedure of wilt u nog iets anders kwijt?
Ik zal me er wat meer in moeten gaan verdiepen.
Voor de systeemkeuze is de procedure nuttig. Het verwijzen binnen OVS'n vind ik onjuist. Als TPL doe je daar niets mee en de reviewers kijken hier volgens mij niet naar
Wil meer weten over RAMSHE LCM in relatie met ondergrondse infra projecten.
Het principe is goed en heeft toegevoegde waarde, maar borging binnen ProRail was niet goed geregeld.
Ik merk dat er te weinig kennis en ervaring is binnen Railtechniek om meer 'te doen' met RAMSHE LCM.
RAMS/LCM is een mooie tool, maar hij dient ook met verstand gebruikt te worden en ik mis de economische en duurzaamheidstoets
De toegevoegde waarde zit erin als het verder gaat dan open deuren en algemeenheden die op elk project gelden.
Nee
Werkt het in de keten Planontwikkelaar, TPL en bouwmanager
Nee.
Er is altijd een dubbele boodschap aan projecten. Enerzijds voldoen aan honderdduizend voorschriften die de RAMS-kwaliteit sterk bepalen, anderzijds mag je aantonen of die kwaliteit wel in orde is.
Heeft de procedure overlap met het werk van de paar Maintenance Engineers die binnen onze AM afdeling aan het werk zijn? Ik denk dat hun inzet, samen met deze procedure, tot een betere projectscope zou kunnen leiden bij aanvang van het project.

Er wordt te veel informatie verzameld waardoor er geen goed overzichtelijk dossier wordt opgesteld. Deels ook overlappend met andere procedures zoals DISP (ORC00256)

Nee

B Kernproces Informatieoverzicht HSWI project



C Semi-structured interview guide

Before conducting the semi-structured interviews, the participants have been given a short explanation of the research through email.

At the start of the interview we explained the benefits of the research, which is that contributing to the research can help with the improvement of the procedure. Furthermore, it is explained that the participant has the right to withdraw from the research at any given time without any consequences. Lastly, we ask if we have the consent of the participant to start with the interview.

First we repeat the goal of the interview with the following bullet points:

- Form an image of the experiences and the perspective of the involved functions;
- Determine what the preferred output of the procedure is / what the purpose of the procedure is;
- Discover the characteristics that are Critical To Quality according to the interviewee;
- Possibly already identify bottlenecks.

The questions are divided into different categories and function as a guidline for the interview. Other questions are asked whenever necessary following the flow of the interview.

Function:

Could you shortly explain what your function within ProRail entails?

Knowledge:

To what extent are you familiar with the RAMSHE LCM procedure?
Are you aware of your role within the procedure? How would you describe it?

Value:

What is the purpose of applying RAMSHE LCM from your perspective?
What is in your perspective the most important output of the procedure?
What are the most important activities or steps within the procedure?

Bottlenecks:

Are you running into any issues within the procedure?
If you could make any changes to the way the procedure currently works, what would you change?

Other:

Is there anything that we have not discussed yet that you still wish to share about your experiences with RAMSHE LCM?

D Empty survey

On the following pages, the questions of the survey as sent to the research population are shown.

Afstudeeronderzoek PRC00290

ExpertReview-score Redelijk

Introductie

Q1

Ga naar

Einde enquête als Ik geef geen toestemming, i... is geselecteerd

Beste ProRailer,

Voor mijn afstudeeronderzoek ben ik bezig met het in kaart brengen van de waarde van PRC00290, ook wel bekend als de RAMSHE LCM procedure. U heeft deze enquête ontvangen omdat u volgens de procedure een rol speelt in de uitvoering van het RAM stappenplan (PRC00290). Deelname aan deze enquête wordt enorm gewaardeerd en draagt mogelijk bij aan de verbetering van de procedure. Ook wanneer u niet bekend bent met de procedure, dragen uw antwoorden bij! Uw antwoorden zullen volledig vertrouwelijk behandeld worden.

De survey zal slechts enkele minuten duren en deelname aan dit onderzoek is vrijwillig. U heeft het recht om u op elk moment terug te trekken uit dit onderzoek. Mocht u meer willen weten over het onderzoek dan kunt u mij bereiken via anne.hoogeveen@prorail.nl.

Door op onderstaande knop te klikken, erkent u dat de deelname vrijwillig is en dat u zich op elk moment, ongeacht de reden, terug kunt trekken uit dit onderzoek.

Deze survey is het best zichtbaar op een laptop of computer. Sommige features werken minder goed op een telefoon of tablet.

- ○ Ik geef toestemming, start de enquête
- ○ Ik geef geen toestemming, ik wil niet deelnemen aan dit onderzoek

Importeren uit bibliotheek Nieuwe vraag toevoegen

Blok toevoegen

Blok 1

Q2 *

Wat is uw functie?

- ○ Technisch Projectleider
- ○ Plancoördinator
- ○ Planontwikkelaar
- ○ Bouwmanager
- ○ Projectmanager
- ○ Anders, namelijk:

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Blok 2

Q4 *

Bent u bekend met RAM, RAMS, RAM-LCM of RAMSHE-LCM? Heeft u er van gehoord?

- ○ Ja
- ○ Nee

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Blok 6

Q10

Deze vraag weergeven

Als Bent u bekend met RAM, RAMS, RAM-LCM of RAMSHE-LCM? Heeft u er van gehoord? Nee is geselecteerd

RAMSHE LCM staat voor Reliability, Availability, Maintenance, Safety, Health, Environment en Life cycle management. RAMSHE LCM wordt toegepast als ondersteuning bij besluitvorming over alternatieven, als inschatting van de toekomstige prestatie en kosten van een systeem en als onderbouwing dat het systeem voldoet aan de regelgeving.

Q13 ✳

Deze vraag weergeven

Als Bent u bekend met RAM, RAMS, RAM-LCM of RAMSHE-LCM? Heeft u er van gehoord? Nee is geselecteerd

Ga naar

Einde enquête als Ja, ik ben dit niet tegenge... is geselecteerd

Bent u nog steeds onbekend met RAMSHE LCM?

- ◯ Ja, ik ben dit niet tegengekomen in mijn werk
- ◯ Nee, ik ben er bekend mee, maar was niet bekend met de afkortingen

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Blok 7

Q9

Een korte toelichting over PRC00290: Dit stappenplan geeft een beschrijving van de stappen die nodig zijn om het RAM proces binnen een infraproject goed en effectief te doorlopen. Het geeft de Projectmanager, Plancoördinator en de projectmedewerkers inzicht en overzicht in de verschillende stappen die ervoor zorgen dat RAM op een gestructureerde en geborgde manier wordt toegepast in een project. De verantwoordelijkheden van de betrokken functies zijn per stap aangegeven in een RASCI-tabel.

Het stappenplan is nadrukkelijk niet van toepassing voor Functiehandhaving (projectmatige werkzaamheden op het vlak van beheer, onderhoud, vervanging en renovatie van de bestaande infrastructuur) en Omgevingsprojecten (werkzaamheden binnen de vergunningsgrenzen maar zonder vervoerscomponent (incl. transfer).

Q11 ✳

Ga naar

Einde enquête als Nee ik heb alleen ervaring ... is geselecteerd

Werkt u (of heeft u ooit gewerkt) in projecten die in aanmerking komen voor RAMSHE LCM studies?

- ◯ Nee ik heb alleen ervaring met Functiehandhaving en/of Omgevingsprojecten
- ◯ Ja

Q5

Ga naar

Einde enquête als Nee is geselecteerd

Kent u PRC00290? Ook wel 'het stappenplan RAM' genoemd.

- ○ Ja
- ○ Nee

Q6

Heeft u PRC00290 ooit gebruikt?

- ○ Ja
- ○ Nee

Q12

Maakt u actief gebruik van PRC00290 in uw werk?

- ○ Ja
- ○ Nee, want

Q18

Is het voor u duidelijk wat het doel/de waarde van de procedure is?

- ○ Ja, namelijk:
- ○ Deels, namelijk:
- ○ Nee, want:

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Blok 5

Q23

Prestatie procedure:
Op basis van meerdere interviews is een lijst met eigenschappen samengesteld die een rol spelen in het presteren van de procedure. Met de volgende stellingen willen wij in kaart brengen hoe de procedure presteert op het gebied van deze eigenschappen. Met een 5-punts likert schaal kunt u aangeven in hoeverre u het eens bent met de stellingen. Beantwoord deze stellingen vanuit uw eigen ervaringen.

Q7

In hoeverre bent u het eens met de volgende stellingen?

	Helemaal oneens	Oneens	Neutraal	Eens	Helemaal eens
Ik beschik over voldoende kennis om mijn rol binnen de procedure uit te voeren	○	○	○	○	○
De procedure is makkelijk te begrijpen	○	○	○	○	○
Ik heb voldoende tijd om mijn rol binnen de procedure uit te voeren / RAMS toe te passen in mijn werk	○	○	○	○	○
De procedure is makkelijk te vinden / toegankelijk	○	○	○	○	○
De beschreven stappen zijn altijd uitvoerbaar	○	○	○	○	○
Het is mogelijk om af te wijken van de procedure wanneer dit nodig is (bij een specifieke situatie)	○	○	○	○	○
De procedure wordt door de betrokken spelers op dezelfde manier geïnterpreteerd	○	○	○	○	○
Er worden specifieke RAM eisen (de gewenste RAM-prestaties/doelen van een systeem) meegegeven aan het begin van de procedure.	○	○	○	○	○
De benodigde informatie/input voor het uitvoeren van uw rol binnen de procedure is altijd compleet	○	○	○	○	○
De benodigde informatie/input voor het uitvoeren van uw rol binnen de procedure wordt tijdig geleverd	○	○	○	○	○
Het uitvoeren van RAMSHE LCM wordt gecontroleerd/gemonitord	○	○	○	○	○
De uitkomst van de procedure is zichtbaar nuttig en wordt gebruikt bij andere afdelingen van ProRail	○	○	○	○	○

Q18

Wilt u nog iets toelichten over voorgaande stellingen?

Q15

De volgende stellingen gaan over het RAMSHE LCM dossier. Het RAMSHE-LCM dossier bevat de zaken die relevant zijn om vanaf de dag van indienststelling het beheer en onderhoud goed te kunnen organiseren en uitvoeren, denk aan resultaten van de uitgevoerde analyses en kosten van beheer en onderhoud over de levensduur. Tijdens de procedure wordt het dossier meerdere keren aangevuld met RAM gerelateerde onderwerpen. Het definitieve RAMSHE LCM dossier wordt (volgens het stappenplan) aan het einde van de procedure overgedragen aan de Gebiedsmanager DO. AM richt zich vervolgens op het beheer, onderhoud en prestatiemonitoring van de nieuwe infra.

Vul de vragen in op basis van uw eigen ervaringen met de procedure.

Q16

In hoeverre bent u het eens met de volgende stellingen?

	Helemaal oneens	Oneens	Neutraal	Eens	Helemaal eens
Het is duidelijk hoe en welke onderdelen van het definitieve RAMSHE dossier gebruikt worden door AM	○	○	○	○	○
Er staat geen overbodige informatie in het dossier: Het definitieve dossier bevat alleen relevante informatie nodig voor het inrichten van beheer, uitvoeren van onderhoud en monitoren van de prestatie.	○	○	○	○	○
Bestaande RAMSHE dossiers zijn altijd beschikbaar als input voor nieuwe RAMSHE studies/projecten	○	○	○	○	○

Q20

Wilt u nog iets toelichten over voorgaande stellingen?

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Blok 7

Q19

Belang eigenschappen:
Met voorgaande stellingen is gemeten in hoeverre de procedure presteert op bepaalde eigenschappen. Met de volgende vraag willen we in kaart brengen in hoeverre de eigenschappen waarde toevoegen en belangrijk zijn voor het succes van de procedure. Het gaat hier dus niet over het presteren van de eigenschappen zelf, maar in hoeverre een eigenschap invloed heeft op het succes van de procedure. Bijvoorbeeld: Hoe belangrijk is het dat de uitvoering van de procedure gemonitord wordt?

Q20

Op een schaal van 1 tot 10, in hoeverre denkt u dat de volgende eigenschappen waarde toevoegen aan / van belang zijn voor het presteren van de procedure? (1 = voegt geen waarde toe , 10 = voegt heel veel waarde toe en heeft dus veel impact op het presteren van de procedure)

	1	2	3	4	5	6	7	8	9	10
Kennis onder medewerkers	○	○	○	○	○	○	○	○	○	○
Duidelijkheid van de procedure (makkelijk te begrijpen, overzichtelijk)	○	○	○	○	○	○	○	○	○	○
Tijd/capaciteit voor het uitvoeren van procedure	○	○	○	○	○	○	○	○	○	○
Vindbaarheid van procedure	○	○	○	○	○	○	○	○	○	○
Uitvoerbaarheid van stappen	○	○	○	○	○	○	○	○	○	○
Flexibiliteit (hoe makkelijk je af kan wijken)	○	○	○	○	○	○	○	○	○	○
Eenduidigheid (de procedure kan maar op 1 manier geïnterpreteerd worden)	○	○	○	○	○	○	○	○	○	○
De aanwezigheid van specifieke RAM eisen aan het begin van de procedure	○	○	○	○	○	○	○	○	○	○
De aanwezigheid van de benodigde informatie/input voor het uitvoeren van de procedure	○	○	○	○	○	○	○	○	○	○
Tijdig ontvangen van benodigde informatie/input voor het uitvoeren van de procedure	○	○	○	○	○	○	○	○	○	○
Controle en monitoring van de uitvoering	○	○	○	○	○	○	○	○	○	○
Duidelijkheid van het doel/nut	○	○	○	○	○	○	○	○	○	○
Kennis over gebruik van het definitieve RAMSHE dossier	○	○	○	○	○	○	○	○	○	○
Beknoptheid van het definitieve RAMSHE dossier	○	○	○	○	○	○	○	○	○	○
Beschikbaarheid van bestaande dossiers als input voor nieuwe RAMSHE studies	○	○	○	○	○	○	○	○	○	○

Q21

Wilt u nog iets toelichten over voorgaande stellingen?

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Blok 8

Q22

Het doel van dit onderzoek is om de waarde van de procedure duidelijk te maken en in kaart te brengen wat de knelpunten zijn om zo de verspillingen uit de procedure te halen. Denkt u dat u de procedure in de toekomst vaker zal gebruiken wanneer het nut duidelijker is en de knelpunten zijn aangepakt?

- Ja
- Nee, want

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Blok 6

Q17

Wilt u nog iets extra's toevoegen over uw ervaringen met de RAMSHE LCM procedure of wilt u nog iets anders kwijt?

Importeren uit bibliotheek | Nieuwe vraag toevoegen

Blok toevoegen

Bedankt voor uw tijd! Uw antwoorden zijn geregistreerd.

Mocht u nog vragen of opmerkingen voor mij hebben, schroom dan niet om een bericht te sturen op anne.hoogeveen@prorail.nl of op mijn studentenmail a.hoogeveen@student.utwente.nl.

Met vriendelijke groet,

Anne Hoogeveen

E Survey results

In this section, the full explanations given by respondents to support their answers are shown. These are directly translated from the Dutch responses given by the respondents and not further edited in any way.

E.1 Active use of the procedure

Why do you not actively use PRC00290 in your work?

- It is dependent on the number of FW (Function Change) projects.
- I know about its existence, but I do not work with it myself.
- My activities mostly concern retention, not design.
- There are many standard components of which the LCM numbers are known.
- I'm not going to go into that right now, but something concerning money.
- I just have to make sure we include it in the project, but I have nothing to add myself.
- Delegated it.
- I only have to deal with it occasionally.
- Less prominent in this phase of the project.
- For a while now, I have had more projects in the design phase.
- As a Plan Coordinator I have many projects where this does not apply. The procedure is in my experience also not generally known within the project teams.

E.2 Perceived value of the procedure

Is it clear to you what the value/purpose of the procedure is?

Yes, namely:

- To create concrete actions and agreements for changing and transferring infra to the management organization Asset Management;
- Important tool for making sure that the RAM aspects get taken into account timely and fully in the exploration and planning & study phase.
- Making a trade-off between functionality and RAM;
- For me: include management interests in weighing up options and transfer relevant choices and information at the end of the project;
- Structurally making a design choice;
- Ensures that the RAMSHE-LCM aspects are actively considered during the project and that well-considered choices are made AND that these choices are also recorded in the appropriate documents so that the manager is ultimately ready to manage the modified infrastructure.
- Investigating the RAMSHE-LCM aspects fitting with the phase in the Kernproces;
- So that it can be taken into account when considering an alternative (usually this is not decisive for the choice) and so that after the execution of a project AM can indicate how their maintenance costs have changed and whether they can then receive more or less from the ministry;
- Make a choice between variants based on performance. Higher installation costs can be cheaper in the long term due to lower nuisance costs, lower installation costs can lead to higher nuisance costs in the use phase. You have to weigh this up carefully;
- Contribute to better RAM performances;
- Dividing the responsibilities of the RAMSHE process during the different phases of a project;

- Ensuring that the RAMSHE aspects are included well;
- A project that is maintainable and delivers an optimal performance;
- Embedding the RAMSHE attributes in the design that is to be realized;
- Clear input and output of activities and involved players;
- Building with the best life cycle value.

Partly, namely:

- In general somewhat clear;
- When applied products deviate from SPC's (assumption: specifications).

No, because:

- There is a lot of overlap between products that explain the effects on RAMSHE aspects. Examples are: business case, MKBA (social cost benefit analysis) and FIS (Railverkeer Technisch Funtioneel Integraal Systeemontwerp);
- During the design we barely focus on LCM or take this into account in our designs.

E.3 Explanations CTQ statements

The following explanations were given after we asked whether the respondents still wanted to give an additional explanation about the CTQ statements:

- The procedure ensures the good and well needed execution of the RAM process if all the involved players use it the right way;
- As a Plan Developer, I am not usually in the lead once the planning & studies phase starts. I have given the answers based on my experiences with RAMSHE during the exploration phase of projects;
- Especially the information sources about the current infrastructure are insufficient, for example the load capacity of a work of art from 1950 for a new and future situation;
- Asset Management can go too far in asking for manuals and failure rates while there are no experience figures for new matters and we as ProRail are therefore taking a risk. Not everything can be solved down to the last decimal point. Apart from that, my experience is that after project completion and extensive reports, manuals or analysis, AM only looks at the difference in maintenance costs and the other matters immediately disappear into the eternal archive;
- I do not understand that colleagues do not execute the procedure and still are allowed to continue in the Kernproces...
- You often have to carefully consider yourself which RAM goals have to be aimed for and how this is shown. RAM seems to play an especially relevant in the starting phase of a project (plan development). Once design choices have been made, the biggest opportunities have been seized;
- Because a lot is prescribed within ProRail, there is little time and space for RAMS optimalization. The procedure suggests that that space is there and is therefore generally too extensive. In the worst case you are asked to show the RAMS quality of a solution that is already mandatory (when I am obliged to apply something, I think the RAMS quality should be shown by the person that is obliging);
- "The described steps are always executable". The point is to consciously deviate from the steps that do not add value.;
- "Specific RAM requirements are given beforehand": This is not applicable in any project, because ProRail has no idea how a project contributes to the performance of the entire country. There are country wide KPI's, but you can not translate those. The point is to create insight into the performance, without a specific requirement.
- The procedure has a lot of potential, but it is not yet sufficiently implemented.

The following explanations were given specifically about the statements concerning the RAMSHE dossier:

- I think that RAMSHE LCM is useful for asset management. It is difficult for me to estimate what they do with it exactly, but it is a clear selection. I think can be easily checked what ends up in the PGO (proces gericht onderhoud), SAP and V&G dossiers.
- In my experience, the dossier is only used to indicate the difference in maintenance costs in a new system. Other documents disappear and definitely do not appear at new projects, even when asked.
- I have never really transferred a real dossier, only coordinated it to make decisions about variants.
- I am not familiar with the use of the RAM dossier at commissioning. I thought that it was mostly important during the early design phase.
- I think everyone will answer this question similarly. There are no RAMS/LCM dossiers. But if we do not ask this from the projects, they will never be there.

E.4 Rating CTQ importance

The following additional explanations were given after the respondents were asked to rate the importance of the CTQs:

- RAMSHE - LCM is already being researched, caluclated and more in multiple other products within ProRail. Examples are the FIS, MKBA, Businesscase and usually also CE products. The procedure seems to connect all the separate procedures, but does this by asking for even more products like the RAMSHE dossier.
- Actually all statements are important, but one follows from the other. I think the input part is especially important. Often assumptions are being made that are seen as truth and serve as a basis for showing the quality. That is a shaky principle.
- We should stand up for the quality of our procedures and the connected products. That way we also earn back our investments. Rubish in is rubish out. Regarding flexibility within the procedure I have indicated that we should not want that. We are working towards standardization which can in return serve as useful input for the next step.
- We should only focus on the end goal. If it turns out that only the costs of the different designs differ, then we should not ask for more than the costs. That also becomes visible from the dossiers that we need to deliver. If there have never been made any changes by for example PGO then it is probably also not being used.
- In order of importance: 1) The client knows what they want regarding RAM (they set clear requirements and wishes). 2) There is enough knowledge about the methods to evaluate RAM performances (how are we going to prove it). 3) Beforehand clear agreements are made with the client about how the procedure is applied and which steps are performed.
- It all hinges on the availability and reliability of the existing dossier.
- The availability of specific RAM requirments at the start of the procedure is only useful if there is an accepted (simple and efficient) method of proving that you adhere to the requirement for every requirement.
- I scored knowledge among the employees with a ten. This is very important, but currently not the case.