The application of Systems Engineering in major infrastructure maintenance projects

A research into the improvement of the methods and processes of Rijkswaterstaat

Master Thesis
Construction Management & Engineering

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Eindhoven University of Technology
In collaboration with Rijkswaterstaat

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"If I had asked my customers what they wanted,
they would have said faster horses."

Henry Ford

Colophon

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Preface

This thesis is the result of my graduation research, which concerns the application of Systems Engineering in major infrastructure maintenance projects. This graduation research is the final part in order to complete my master Construction Management & Engineering at the University of Technology in Eindhoven. I would like to thank my supervisor from the TU/e, Wiet Mazairac, for ultimately creating insight and clarity at all times, it was worth traveling.

This graduation research was carried out for and in collaboration with Rijkswaterstaat, I would also like to thank those involved of Rijkswaterstaat for their commitment, cooperation, knowledge sharing and the high degree of job satisfaction. In particular, I want to thank Michael Mos for the guidance and infinite learning moments, every inch of you is SE. Also, Sietske Kings has supported me on many occasions during this period without expectations.

At last but not least, this thesis has been made possible by my parents, thanks for your unconditional support and trust. Also, Marlous Cnossen has given me a lot of inspiration and food for thought with her always catchy quotes. Together with Thijs Goijers, they supported me through non-thesis-related moments and provided the necessary distraction (and sleep).

Romy Ran

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Contents

Summary

Rijkswaterstaat is in the field of Systems Engineering (SE), one of the leading organizations in the Netherlands. Within Rijkswaterstaat, the theory and general principles of SE have been translated and converted into a process description. This process description describes in a clear and unambiguous way the application of SE, specifically for large infrastructural projects within Rijkswaterstaat. The process description should be applicable for every project environment, project situation and project phase, thus therefore for large infrastructure construction projects as well as maintenance projects. Both theory and practice show that the application of SE in construction projects is of added value and ensures greater effectiveness and efficiency. However, the application of SE in maintenance projects is still unknown and therefore difficulties are experienced with the implementation and application of SE within these maintenance projects. These difficulties are caused, among other things, by the different contract types that are applicable in construction and maintenance projects. Due to the presence of these different contract types, it is often unclear and unknown to what extent the scope and abstraction level of projects should be specified. Within the IPM-teams of Rijkswaterstaat, who actually have to apply the process description, there often is insufficient knowledge from SE in order to solve these difficulties themselves. As a result, the final product of the process description, the contract specification (the client's request to potential contractors), often does not meet the desired, prescribed and necessary quality. Therefore, the aim of this research is to ensure that the application of SE, thus the process description, also becomes applicable for large infrastructure maintenance projects, so that these projects can also be managed in a more effective and efficient way in the future.

First of all, examined is which **general principles** of **SE** ensure the successful application of SE in large infrastructural projects. The literature shows that the application of five general principles can ensure the successful application of SE. all these general principles are equally important and interrelated, these general principles of SE relate to an integral approach, systems thinking, customer management, design flexibility and requirements management. Subsequently, it was examined whether these five general principles of SE found from the literature, correspond with the general principles of SE that Rijkswaterstaat applies in practice. This research shows that the general principles of Rijkswaterstaat correspond with those from the literature, from which it can be concluded that the difficulties encountered with the application of SE in maintenance projects are not caused by this aspect.

Subsequently, the **differences** between **construction and maintenance projects** were examined in order to find out why the application of SE in maintenance projects is still unexplored area. The characteristics of construction and maintenance projects to which these projects can be compared and which also relate to the area of SE, are as follows; contract types, scope, stakeholders, abstraction level, design flexibility and project phases. It was expected that large differences between these two processes would be identified, this also seems to be the case at first glance, when looking at the identified differences between construction and maintenance projects. For instance, construction projects apply completely different contract types (D&C and DBFM contracts) in contrast to maintenance projects (E&C and performance based contracts), the scope in construction projects is mostly large and new, therefore many stakeholders are involved in this process, while the scope in maintenance projects is mostly small and already existing, as a result of which few stakeholders are involved in this process. However, even though these differences seem to be large, all identified differences are, above expectations, fairly small and not so different to a certain level, as a result of which the construction and maintenance projects are still largely comparable in the field of SE. Despite the identified differences in all characteristics between both processes, both construction and maintenance projects roughly go through the same project phases and the associated activities, such as the activities relating to the design process, the specification thereof and all activities relating to the stakeholders involved. All these activities are largely comparable, up to a certain level, and remain substantially the same in both construction and maintenance projects.

After the general principles of SE and the differences between construction and maintenance projects have been investigated and established, **bottlenecks** in the application of the process description in maintenance projects have been identified with the aid of a case study project of Rijkswaterstaat. The identified bottlenecks relate to the following aspects; bureaucracy, terminology, role division, stakeholders management, V&V, the design process and analyzing the project assignment. All these bottlenecks can be traced back to the general principles of SE and are can often be explained by the different properties of construction projects in relation to maintenance projects, since there is often the illusion that various activities do not or cannot be carried out in maintenance projects. Despite the fact that these illusions are often not correct, these illusions still occur because certain activities, that need to be carried out as well in construction as maintenance projects, are simply not recognized in maintenance projects and are therefore not carried out. The identified bottlenecks therefore often relate to difficulties encountered in recognizing and translating the SE theory into the practical maintenance projects of Rijkswaterstaat.

Thereafter, a lay-on note for the process description has created, which only applies to large infrastructure maintenance projects, in order to eliminate all the identified bottlenecks. In this so-called **process model**, some changes, additions or exceptions to the already existing process description are described and substantiated with the aim to create awareness of the fact that almost always the same SE theory and general principles are applicable for both construction and maintenance projects. This awareness is created by translating the same SE theory into practical and maintenance-oriented examples, this makes for example clear that also in maintenance projects, despite a smaller number of stakeholders or making design choices at a lower level of abstraction, the same SE theory and general principles, as in construction projects, are applicable. Therefore, the process model provides the connecting factor and the translating from theory into practice, whereby the identified bottlenecks can be eliminated. From now on, the process model is actually consulted by the IPM-teams of Rijkswaterstaat, in order to carry out the maintenance projects in a more effectively and efficiently way with the use of SE. however, due to the use of a case study project of Rijkswaterstaat, the process model was specifically developed for a select type of maintenance project and region within Rijkswaterstaat. It is therefore advisable to introduce and implement the process model in several types of maintenance projects and regions within Rijkswaterstaat, in order to be able to work in a more uniform, effective and efficient way in the future.

In order to be able to carry out maintenance projects even more effectively and efficiently in the future, it is also of great importance that all information from maintenance projects can be managed in a digital information management system. Within Rijkswaterstaat, GRIP in Relatics is used for this purpose. This requires that an **information model** must exists for all crucial information in maintenance projects, in order to process, merge and manage all information. However, until know, the information model of an important maintenance specific element is lacking, namely the measure element, which is used within Rijkswaterstaat to express the activities related to major variable maintenance that need to be carried out. It is important to investigate and determine what a measure actually entails, how it arises and how it relates to other elements in maintenance projects. An information model is created for the measure element, among other things consisting of the fact that a measure emerge by an observed damage at all times, a measure also always relates to an object and a measure must always be created and recorded in a source document. The final information model for the measure element is tailored to the already existing information models of Rijkswaterstaat and therefore can be easily translated into a digital model in the future, so that it can seamlessly be integrated and connected to the digital information management system of Rijkswaterstaat. As a result, that maintenance projects can also be managed in GRIP in the future, to increase the effectiveness and efficiency.

Samenvatting (Summary in Dutch)

Rijkswaterstaat is op het gebied van Systems Engineering (SE) één van de toonaangevendste organisaties van Nederland. Binnen Rijkswaterstaat zijn dan ook de principes, theorie en het gedachtegoed van SE vertaald in een procesbeschrijving, deze procesbeschrijving beschrijft op een duidelijke en eenduidige manier de toepassing van SE, specifiek gericht op grote infrastructurele projecten binnen Rijkswaterstaat. De desbetreffende procesbeschrijving zou toepasbaar moeten zijn voor elke project omgeving, project situatie en project fase, ofwel toepasbaar voor zowel grote infrastructurele aanleg- als onderhoudsprojecten. Uit zowel de theorie als uit de praktijk blijkt dat de toepassing van SE in aanlegprojecten van toegevoegde waarde is en zorgt voor meer effectiviteit en efficiëntie. Echter, is de toepassing van SE in onderhoudsprojecten tot voorheen nog onbekend en worden dus moeilijkheden ervaren met de implementatie en toepassing van SE binnen deze onderhoudsprojecten. Deze moeilijkheden worden onder andere veroorzaakt door de verschillende contractvormen die van toepassing zijn in aanleg- en onderhoudsprojecten, door de aanwezigheid van deze verschillende contractvormen is het vaak onduidelijk en onbekend tot op welk niveau de scope en het abstractieniveau van projecten zou moeten worden gespecificeerd. Binnen de IPM-teams van Rijkswaterstaat, die de procesbeschrijving daadwerkelijk moeten toepassen, is vaak ook onvoldoende kennis van SE om deze moeilijkheden zelf op te lossen. Dit heeft als gevolg dat het eindproduct van de procesbeschrijving, de contractspecificatie (de uitvraag van de opdrachtgever aan potentiele opdrachtnemers), vaak niet voldoet aan de gewenste en noodzakelijke kwaliteit. Het doel van dit onderzoek is dan ook om ervoor te zorgen dat in de toekomst de toepassing van SE, ofwel de procesbeschrijving, ook van toepassing is in grote infrastructurele onderhoudsprojecten, zodat ook deze projecten op een effectieve en efficiënte manier kunnen worden gemanaged.

Allereerst is onderzocht welke **algemene principes** van **SE** zorgen voor een succesvolle toepassing van SE in grote infrastructuur projecten. Uit de literatuur blijkt dat de toepassing van vijf algemene principes kan zorgen voor een succesvolle toepassing van SE. Al deze algemene principes zijn even belangrijk en zijn onderling met elkaar verbonden, deze algemene principes van SE hebben betrekking op een integrale aanpak, het systeemdenken, klantmanagement, ontwerpvrijheid en eisenmanagement. Vervolgens is onderzocht of deze vijf algemene principes van SE uit de literatuur overeenkomen met de algemene principes van SE die Rijkswaterstaat toepast in de praktijk. Uit deze analyse blijkt dat de algemene principes van Rijkswaterstaat overeenkomen met die uit de literatuur, hieruit kan worden geconcludeerd dat de moeilijkheden, die worden ondervonden met de toepassing van SE in onderhoudsprojecten, niet door dit aspect worden veroorzaakt.

Vervolgens zijn de **verschillen** tussen **aanleg- en onderhoudsprojecten** onderzocht, om te kunnen achterhalen waarom de toepassing van SE in onderhoudsprojecten nog onontgonnen gebied is. De eigenschappen van aanleg- en onderhoudsprojecten waarop deze projecten vergeleken kunnen worden en die ook betrekking hebben op het gebied van SE zijn als volgt; contractvormen, scope, stakeholders, abstractie niveau, ontwerpvrijheid en project fases. Verwacht was dat grote verschillen tussen deze twee processen zouden worden geïdentificeerd, dit lijkt ook zo wanneer op het eerste gezicht gekeken wordt naar de geïdentificeerde verschillen. Zo worden in aanlegprojecten totaal andere contractvormen gebruikt (D&C en DBFM contracten) dan in onderhoudsprojecten (E&C en prestatie contracten), is de scope in aanlegprojecten juist groot en nieuw, waardoor ook veel stakeholders betrokken zijn in dit proces, terwijl de scope in onderhoudsprojecten juist klein en al bestaand is waardoor weinig stakeholders betrokken zijn in dit proces. Echter, alle geïdentificeerde verschillen zijn, boven verwachting, toch zodanig klein en tot op een bepaald niveau helemaal niet zo verschillend waardoor de projecten toch grotendeels goed vergelijkbaar zijn. Ondanks de geïdentificeerde verschillen in alle eigenschappen tussen beide processen, doorlopen zowel aanleg- als onderhoudsprojecten beide grofweg dezelfde project fases en de daarbij behorende activiteiten, zoals de activiteiten die betrekking hebben op het ontwerpproces, het specificeren hiervan en alle activiteiten met betrekking tot betrokken stakeholders, zijn tot op een bepaald niveau grotendeels vergelijkbaar en al deze uit te voeren activiteiten blijven nagenoeg gelijk.

Nadat de algemene principes van SE en de verschillen tussen aanleg- en onderhouds-projecten onderzocht en vastgesteld zijn, zijn **knelpunten** in de toepassing van de procesbeschrijving in onderhoudsprojecten geïdentificeerd met behulp van een case studie project van Rijkswaterstaat. De geïdentificeerde knelpunten hebben betrekking op de volgende aspecten; bureaucratie, terminologie, rolverdeling, stakeholder management, V&V, ontwerpen en het analyseren van de projectopdracht. Al deze knelpunten zijn terug te herleiden naar de algemene principes van SE en veelal te verklaren door de verschillende eigenschappen van aanlegprojecten in verhouding tot onderhoudsprojecten, veelal bestaat namelijk de illusie dat diverse activiteiten niet uitgevoerd hoeven of kunnen worden in onderhoudsprojecten. Ondanks dat deze illusies veelal niet correct zijn, ontstaan deze toch doordat bepaalde uit te voeren activiteiten simpelweg niet herkend worden in onderhoudsprojecten. De geïdentificeerde knelpunten hebben dan ook veelal betrekking op moeilijkheden die worden ondervonden in het herkennen en vertalen van de SE theorie naar de praktijk, ofwel de onderhoudsprojecten.

Daaropvolgend is een oplegnotitie voor de procesbeschrijving opgesteld, die enkel van toepassing is voor grote onderhoudsprojecten, die de geïdentificeerde knelpunten moet elimineren. In dit zogenoemde **proces model** zijn enkele wijzigingen, aanvullingen of uitzonderingen op de huidige procesbeschrijving beschreven en onderbouwd met als doel om bewustwording te creëren van het feit dat grotendeels dezelfde SE theorie en algemene principes van toepassing zijn voor zowel aanleg- als onderhoudsprojecten. Deze bewustwording wordt gecreëerd door dezelfde SE theorie te vertalen naar praktische en onderhoudsgerichte voorbeelden, hierdoor kan duidelijk worden gemaakt dat bijvoorbeeld ondanks een kleiner aantal stakeholders of het maken van ontwerpkeuzes op een lager abstractieniveau, in onderhoudsprojecten, toch dezelfde SE principes van toepassing zijn. Het proces model zorgt hierdoor dus voor de verbindende factor en de vertaling van theorie naar praktijk, waardoor de geïdentificeerde knelpunten kunnen worden geëlimineerd. Vanaf heden wordt het proces model dan ook daadwerkelijk geraadpleegd door de IPM-teams van Rijkswaterstaat waardoor de onderhoudsprojecten met behulp van de toepassing van SE effectiever en efficiënter kunnen worden uitgevoerd, echter door het gebruik van een case studie is het proces model specifiek opgesteld voor een select type onderhoudsproject en regio binnen Rijkswaterstaat. Aan te bevelen is dan ook om in de toekomst het proces model ook te introduceren en implementeren in meerdere type onderhoudsprojecten en regio's binnen Rijkswaterstaat om zo op een meer uniforme, effectievere en efficiëntere manier te kunnen werken.

Om in de toekomst onderhoudsprojecten nog effectiever en efficiënter uit te kunnen voeren is het ook van groot belang dat alle informatie uit onderhoudsprojecten kan worden beheert in een digitaal informatie management beheer systeem, binnen Rijkswaterstaat wordt hiervoor GRIP in Relatics gebruikt. Het is hiervoor noodzakelijk dat van alle cruciale informatie uit een onderhoudsproject een **informatie model** is opgesteld, zodat alle informatie in zijn geheel kan worden verwerkt, samengevoegd en beheerd. Echter, tot op heden mist het informatie model van een belangrijk onderhoud specifiek element, namelijk het element maatregel, dit wordt binnen Rijkswaterstaat gebruikt om de activiteiten aan te duiden die uitgevoerd moeten worden gerelateerd aan het groot variabel onderhoud. Belangrijk is dat wordt onderzocht en vastgesteld wat een maatregel daadwerkelijk inhoud, hoe deze ontstaat en waarmee het samenhangt met andere elementen in onderhoudsprojecten. Met behulp van deze informatie is een informatie model opgesteld voor het element maatregel, zo ontstaat een maatregel ten allen tijde door een geobserveerde schade, heeft een maatregel altijd betrekking op een object en moet een maatregel ook altijd worden opgesteld en vastgelegd in een brondocument. Het uiteindelijke informatie model voor element maatregel is afgestemd op de al bestaande informatie modellen van Rijkswaterstaat en kan hierdoor dan ook in de toekomst gemakkelijker worden vertaald naar een digitaal model waardoor het kan worden opgenomen in en naadloos aansluit op het digitale informatie management beheer systeem van Rijkswaterstaat. Hierdoor kunnen in de toekomst ook onderhoudsprojecten worden beheerd in GRIP, wat de effectiviteit en efficiëntie verhoogt.

List of abbreviations

ATM	Advice Technical Management Advies Technisch Management
DBFM	Design, Build, Finance & Maintain
CM	Contract manager
D&C	Design & Construct
E&C	Engineering & Construct
EM	Environmental manager Omgevings manager (OM)
FBS	Functional Breakdown Structure
GPO	Major Projects & Maintenance Grote Projecten & Onderhoud
IPM	Integral Project Management
KAd	Quality assurance Tenderdossier Kwaliteitsborging Aanbestedingsdossier
MBSE	Model-Based Systems Engineering
MPM	Management project manager Manager project beheersing (MPB)
OBS	Organization Breakdown Structure
PBS	Product Breakdown Structure
PM	Project manager
POF	Project Assignment Form Project Opdracht Formulier
PPO	Programs, Projects & Maintenance Programma's, Projecten & Onderhoud
SE	Systems Engineering
SO&S	System Development & Specification Systeem Ontwikkeling & Specificeren
TM	Technical manager Technisch manager
UML	Unified Modeling Language
V&V	Verification & validation
WBS	Work Breakdown Structure
WNZ	Western Netherlands South West Nederland Zuid

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1. Introduction

Firstly the introduction describes the research motivation and problem definition of this research project, resulting in the demarcated research scope and some related research questions. Secondly, the research design provides insight into how the research process will be completed as structured as possible, to ultimately give a clear answer to the established research questions.

1.1 Research motivation

Rijkswaterstaat is the executive department of the Dutch Ministry of Infrastructure and the Environment that manages and develops the national network of the Netherlands. The mission of Rijkswaterstaat can be summarized by means of three concepts: safety, livability and accessibility. With these three objectives in mind, **Rijkswaterstaat** ensures to manage, develop and maintain the network of high-, rail-, water- and airways in the Netherlands in a sustainable way (Rijkswaterstaat, 2017). Therefore, it is important for Rijkswaterstaat to work process-oriented, unambiguous and integrated with all the various stakeholders and partners. To ensure this, Rijkswaterstaat has merged all the construction and maintenance projects into one main process since 2015, the so-called 'construction and maintenance process' (Rijkswaterstaat, 2016).

All the activities within the main process of construction and maintenance, are activities that involve the preparation and execution of interventions in the physical infrastructure network to maintain, replace, renew or expand the existing network functionality (Rijkswaterstaat, 2016).

Since 2015, the **construction and maintenance process** of Rijkswaterstaat is thus seen as one primary process, while construction interventions ensure that new or extra desired functionality is added to the existing network, in contrast to maintenance interventions which ensure that the existing functionality of the network be maintained. Globally activities have been established to be able to go through this process properly (from the start and preparation of the project up to and including the transfer), both applicable for construction and maintenance projects. However, the completion of the content of these activities has not yet been fully elaborated and does not always apply to both processes. These activities are in fact drawn from the philosophy of construction projects and therefore not always applicable or sometimes even contradictory to maintenance projects (Rijkswaterstaat, 2016).

1.2 Problem definition

Systems Engineering (SE) is one of the work fields of the Advisory Technical Management division, the mission of this field is to ensure that the project teams within Rijkswaterstaat can go through the technical process in construction and maintenance projects in an efficient and effective way with the aid of SE. The development and management of methods, standards or tools is the most common form of advice within this field of work. Probably the most well-known and used product is 'the process description SE for Rijkswaterstaat projects'. The **process description SE** consists of activities descriptions (consisting of a goal, desired input and output and some specific activities for each process step) that must be completed within the construction and maintenance projects of Rijkswaterstaat when applying SE (Rijkswaterstaat, 2016).

"Despite the fact that the process description SE should be applicable in each project environment, project situation and project phase, though the process description SE is not applicable fully for maintenance projects."

The process description SE has been designed with the aim to be applicable in each project environment, project situation and project phase, so the process description SE should be applicable to both construction and maintenance projects. Practice shows that the process description SE is well applicable to construction projects, but unfortunately not yet always applicable or sometimes even contradictory to maintenance projects. This is, as mentioned earlier, because the activities (and its content) of the construction and maintenance process of Rijkswaterstaat are not always optimally elaborated and not always applicable to both processes.

That the process description SE is not applicable fully for maintenance projects is a result of different problems, hypotheses about this have been established:

- Different contract types are applied for construction and maintenance projects, due to the presence of these different contract types, it is often unclear and unknown to what extent the scope and abstraction level of the project should be specified;
- Within the project teams of Rijkswaterstaat there is not sufficient knowledge of SE to designate or solve these problems themselves. Also, there is a lack of SE experts to advise and support the concerned project teams with these difficulties;
- This causes that the final product of the process description SE in maintenance projects (the contract document; which outlines the client's question to potential contractors) often does not meet the desired and prescribed quality

Altogether, the process description SE is not yet fully applicable to maintenance projects of Rijkswaterstaat.

1.3 Research scope

The research is being carried out in collaboration with Rijkswaterstaat, which already and indirectly creates a demarcation of this research. The further demarcation is determined by the two main topics within this research, namely **SE** and **maintenance projects**.

Rijkswaterstaat consist of both national and regional organizational departments (Rijkswaterstaat, 2016). The SE department is one of the work fields of the Advisory Technical Management division, which in its turn is part of the national organization for major projects and maintenance (in Dutch better known as Grote Projecten & Onderhoud (GPO)). The project teams working on maintenance projects are part of the national organization for programs, projects and maintenance (in Dutch better known as Programma's Projecten & Onderhoud (PPO)). At GPO the focus is on processes, to control and manage projects, while the focus at PPO is on the projects themselves. Thus, in all national organizational departments of Rijkswaterstaat, this research focuses only on GPO and PPO.

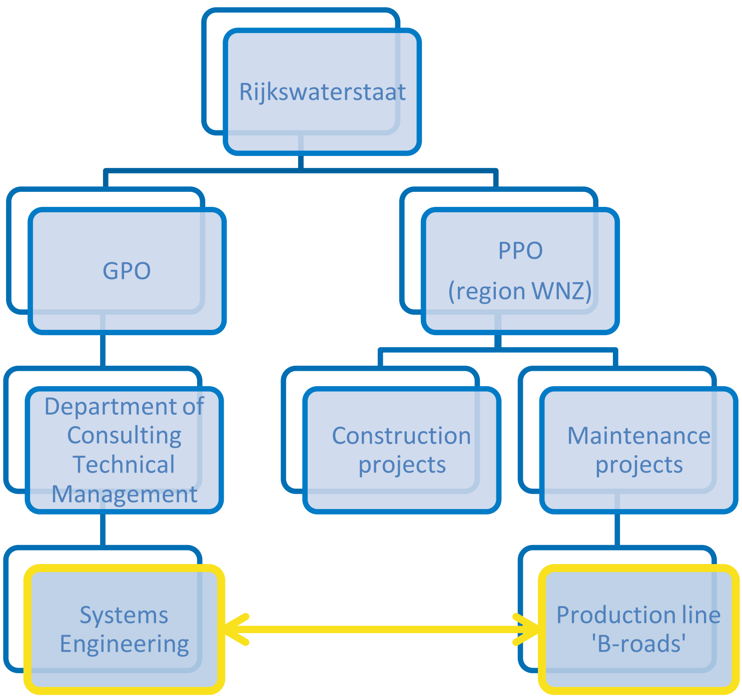


Figure 1.1: OBS of the research scope

Another demarcation has been formed within the regional organization departments of Rijkswaterstaat. This demarcation is based on the availability of case studies of specific maintenance projects under the guidance of a benevolent project team working in the West Netherlands South region (in Dutch better known as West Nederland Zuid). The concerned maintenance projects are part of the **production line B**, briefly summarized these production line B projects consist of variable maintenance on asphalt and concrete hardenings and 'simple' civil structures on state roads (mainly highways) including additional work (the production lines of Rijkswaterstaat are discussed in more detail in chapter 4.2.1).

An overview of all these demarcations together has been made visible in figure 1.1 by using an Organization Breakdown Structure (OBS). This clearly shows the relationship between the two main topics of this research: Systems Engineering and maintenance projects.

The final demarcation is formed by the important role of the process description SE. The process of the **process description SE** starts with a project assignment of the region, this process ends with the development of a contract specification that outlines the client's question (in this case Rijkswaterstaat) to potential contractors. This contract specification is not the final product and goal of the project team, but this is considered to be the ultimate goal for the use of the process description SE. So, for this research the end goal is the contract specification and thus the scope of this research. This final demarcation is made insightful using a BPMN diagram (figure 1.2).

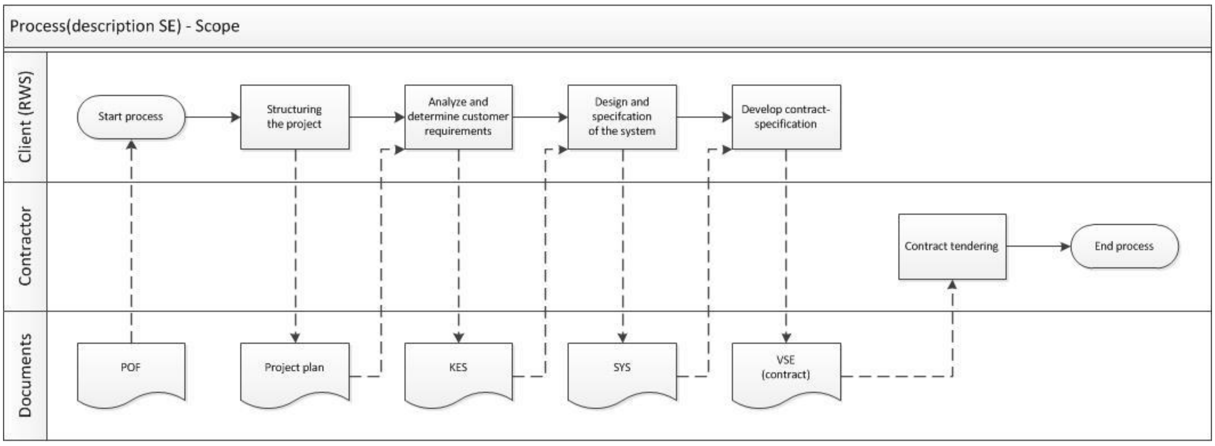


Figure 1.2: BPMN diagram of the research scope

In order to provide an even clearer picture at this last demarcation and to indicate at what point the process description SE applies within the entire Rijkswaterstaat process, this is shown in figure 1.3 below. The figure shows that the final product of the process description, the contract specification, is not the final product of the entire process of Rijkswaterstaat, it is even just at the start.

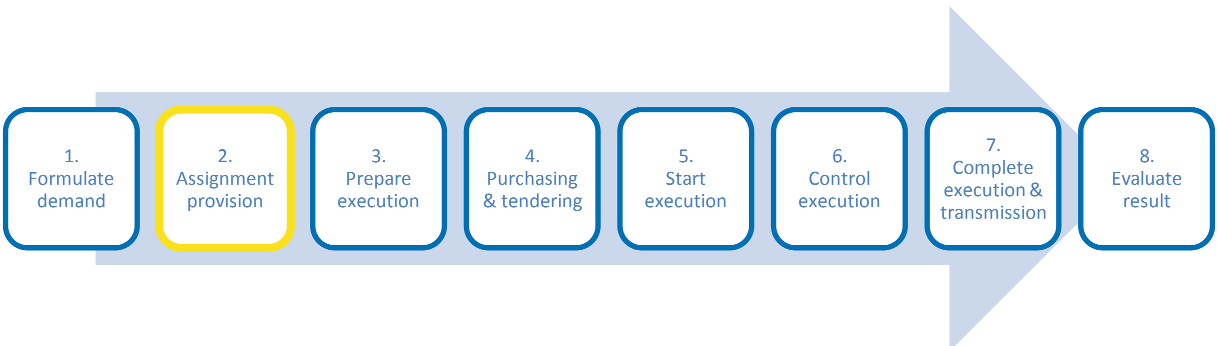


Figure 1.3: Process diagram of the research scope

1.4 Research questions

The previously mentioned and established problem definition and research scope leads to the main research question of this thesis, the main research question is as follows:

"How can the application of Systems Engineering make
major infrastructure maintenance projects more effective and efficient?"

In order to answer the above-mentioned main question as clearly as possible, some sub research questions are defined:

1. "Which general principles of **Systems Engineering** are applied in major infrastructure maintenance projects?"
2. "What are the differences between construction and **maintenance** infrastructure projects?"
3. "Which **bottlenecks** can be identified in the way Systems Engineering is applied in major infrastructure maintenance projects?"
4. "What **improvements** and **advice** can be given to make the application of Systems Engineering in major infrastructure maintenance projects more effective and efficient?"
5. "Which validation **models** (e.g. process model, information model) are suitable to verify the complete and correct application of Systems Engineering in major infrastructure maintenance projects and how can it be applied?"

1.5 Research design

The research model for this thesis was set up to go through the research process as structured as possible and to answer the main questions as clearly as possible. The research model is shown in figure 1.4, further textual explanation of the figure is described below.

The research model consists of three phases: the theoretical research, the qualitative research and the design and development phase. The research begins with theoretical research, which is carried out by means of a literature study on the topics **SE** and construction and **maintenance projects**. The literature study will reveal and gives insight in, among other things, the general principles of SE and the characteristics and differences between construction and maintenance projects. Based on this, the sub research questions 1 and 2 can be answered.

An additional chapter called 'current practice' has also been added in this theoretical phase, which links the findings from the literature study to the current situation within Rijkswaterstaat. This chapter will show how SE is implemented within **Rijkswaterstaat** and which **bottlenecks** arise during the application of SE in maintenance projects, sub question 3 has also been covered by this chapter. Then, the qualitative research is carried out. The case study method and Model-Based Systems Engineering Method are applied, the data need to be collected and processed.

Finally, the design and development phase is gone through. During this phase **models** are designed, implemented and then validated in order to eliminate the bottlenecks and give an **advice** with **improvements** and therefore improve the application of SE in major infrastructure maintenance projects, making the projects and processes of Rijkswaterstaat more effective and efficient. In this last part of this research, sub questions 4 and 5 are covered and will be answered. Eventually, all of the above phases and the corresponding sub conclusions, together form the final graduation thesis.

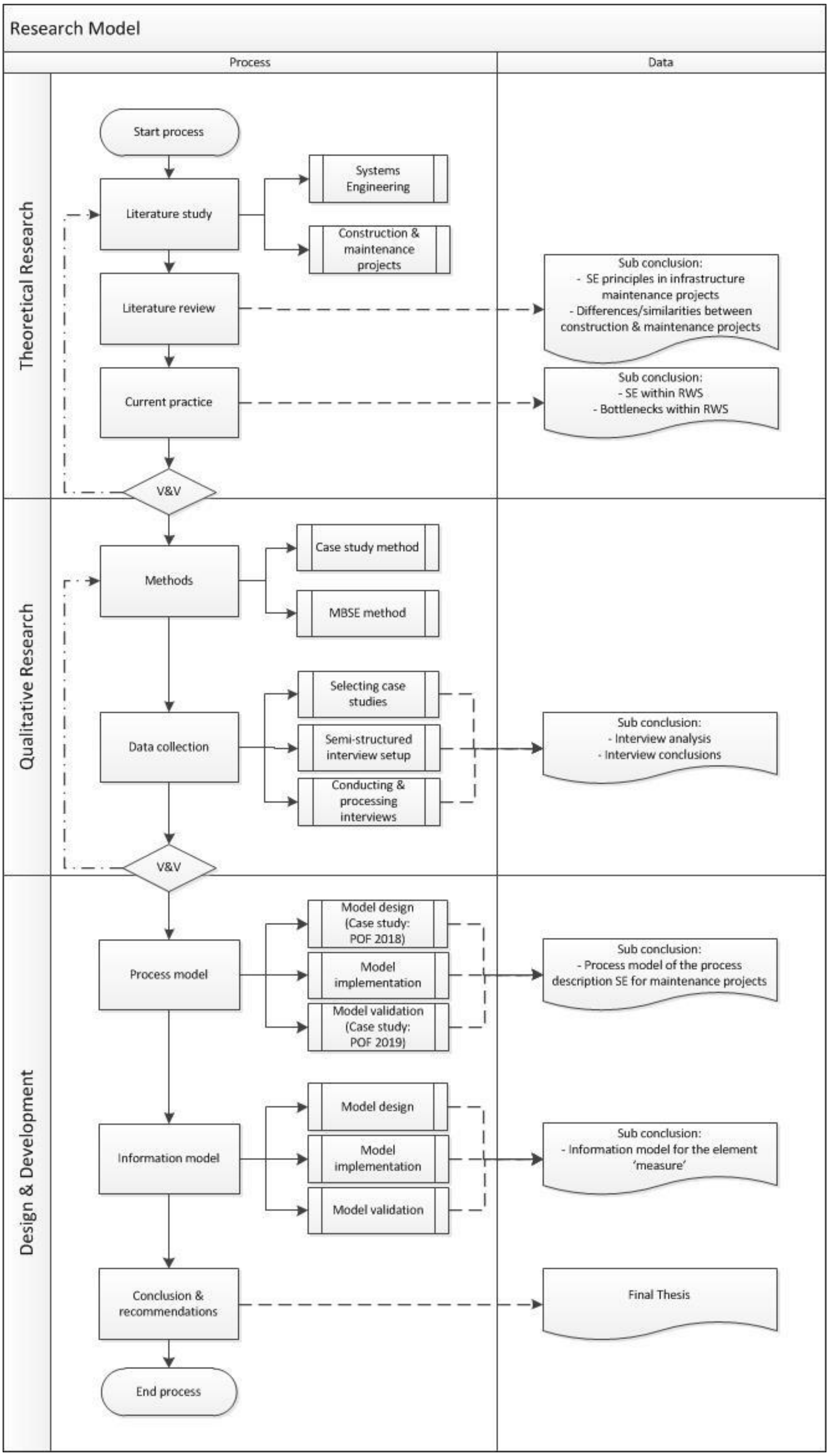


Figure 1.4: BPMN diagram of the research model

2. Literature review

Literature research is carried out on the subjects Systems Engineering and construction and maintenance projects. This chapter provides, among other things, insight into the general principles of SE and in the characteristics and differences between construction and maintenance projects.

2.1 Systems Engineering

2.1.1 Background

History

The application of **Systems Engineering** (SE) was first used in the 40's in the telecommunication sector and was shortly thereafter also used in the development of complex military systems. Later on, SE was further developed in the aerospace sector (Componation, 2015). All the mentioned sectors are known by their complex systems, but with the application of SE the systems were divided into smaller subsystems, which make these systems easier to control and face many complex issues. SE had proved itself, causing more international interest. The International Council on Systems Engineering (INCOSE) focused on the task to further applying and developing SE internationally and gain and share knowledge (INCOSE, 2017). INCOSE-NL originated in the 90's, through this SE was firstly applied within the **civil engineering** sector in the Netherlands (Werkgroep Leidraad Systems Engineering, 2009). Two of the largest Dutch infrastructure clients, Rijkswaterstaat and ProRail, currently are leading and specialized in the application of SE (Rijkswaterstaat, 2017).

Definition

In the course of time, in literature many different interpretations arose for the definition of SE, therefore it is difficult to provide a unique definition of SE. In this research, the definitions of SE that are used by INCOSE Nederland and by the Guide for SE within the civil engineering sector are selected to create a new definition, because these organizations are leading, specialized and applicable to the specific subject of this research, namely SE within infrastructure maintenance projects. Focusing on these two definitions creates more clarity and unambiguity in a renewed and merged definition for this research.

INCOSE is the leading association in the Netherlands that is specialized in the application and development of SE in large infrastructure projects (INCOSE, 2017), the following definition of SE is used: *"An interdisciplinary approach and means to enable the realization of successful systems. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs"* (INCOSE, 2017).

The Guideline for SE within the civil engineering sector is made by members of the four-party consultation, consisting of Rijkswaterstaat, ProRail, Bouwend Nederland, de Vereniging van Waterbouwers, NLingenieurs and UNETO-VNI. According to this guideline, the definition of SE is as follows: *"SE essentially is a structured specification- and design method. SE aims to provide structure and insight into the complexity of the object to be realized. With the help of SE, arising risks from incorrect or incomplete information and assumptions can be controlled. The system is considered as a whole, during the entire life cycle, including its connection with its environment"* (Werkgroep Leidraad Systems Engineeirng, 2007).

Altogether, with these two definitions, a renewed definition is created that is applicable for this research, which applies both internationally and specifically for Rijkswaterstaat:

"SE is an systematic and explicit method, which ensures that complex construction and maintenance infrastructure projects are managed effectively and efficiently in a structured and controlled way. Wherein the customer is the key, satisfaction is created among all the involved stakeholders and a well-functioning integral system is realized within the stated conditions."

Reasons for application

There are several reasons for the introduction of SE within the civil engineering sector, think about e.g. changes in the market, such as more latitude and responsibility, more complex projects and new contract types. The various reasons are divided into political and project management causes with regard to the civil engineering sector.

Political causes:

- Retreating government, which ensures that; (Componation, 2015)
- The market gets more latitude and responsibility in projects, what causes that more tasks will be integrated, which in its turn causes the shifting of tasks and roles; (Rijkswaterstaat, 2017)
- This creates new forms of cooperation and collaboration; integrated contracts (e.g. UAV-gc); (Rijkswaterstaat, 2017)
- With it the need to be able to specify systems at several levels of abstraction (Werkgroep Leidraad Systems Engineering, 2007)

Project management causes:

- The (major) scale of projects (Brunet, 2016)
- The uniqueness of projects (INCOSE, 2012)
- Transferring more and more information (Lopes, 2016)
- Increasing complexity of projects (Boehm, 2012)
- The projects are usually under great time pressure and have a long lifecycle (Huang, 2009)
- Increasingly and previously involved in different phases of the whole process (Celauro, 2017)
- Rapid changes (e.g. customer requirements, new technologies, competitive pressures) (Broniatowki, 2017)
- Cooperating with many and different disciplines and actors (Erkul, 2016)

The above-mentioned new integrated contracts require transparency and better project - and process management. Improved manageability of projects and processes is also necessary to manage complex and unique projects and processes, SE can provide these results.

2.1.2 General principles

In order to fully understand and apply SE, it is important to know how SE manages and delivers successful projects in complex environments. The literature shows that successful SE consists of several principles. In this research, these principles are divided into five general principles, which are directional within the SE process. Of course, SE consists of much more than this, but for this research, this is a useful set of general principles that ensure a successful application of SE. The five general principles of SE are as follows:

1. **Systems thinking**
2. **Integral approach**
3. **Customer management**
4. **Design flexibility**
5. **Requirements management**

Looking at the aim of SE, it is visible immediately that these five general principles are interrelated and cover the purpose of SE: “SE is a multidisciplinary approach (2) (**integral approach**) that is intended to transform a set of stakeholder needs (3) (**customer management**) into a balanced system (1) (**systems thinking**) solution (4) (**design flexibility**) that meets those needs (5) (**requirements management**).” (Steiner, 2015).

Thus, these five general principles ensure that the goals of SE are achieved, the purpose and intent of these general principles will be discussed and described consecutively, but not how or when this should be done (this will follow in the subsequent chapters).

Systems thinking

The first general principle of SE is systems thinking, as the name already says is this thinking in systems. In complex environments, it is useful to think in systems rather than in projects, the focus must be on the entire system and not only on a part of it, a sub-system (Locatelli, 2014). Thinking in systems makes it possible to understand and analyze the various related sub-systems, how they influence each other and finally form a system as a whole (Boehm, 2012).

Systems thinking is also related to the other general principles of SE. By thinking in systems, the system is seen as a whole, not only because of the coherent sub-systems within the system, but also how the system interacts with other external systems and the environment (Steiner, 2015). Through this approach, problems are viewed and combined from various disciplines and therefore becomes a multidisciplinary and interdisciplinary approach (**=integral approach**).

By focusing on a system as a whole through the entire system life cycle, stakeholders and their system of interest are also involved throughout the entire process (**=customer management**) (Locatelli, 2014).

Systems thinking also ensure that the decomposed and designed sub-systems connect and function together as a whole in the most efficient way (**=design flexibility**) (Douglass, 2014).
Finally, thinking in systems provides a structure for a project to be developed, realized and managed in a traceable and verifiable way (**=requirements management**) (Werkgroep Leidraad Systems Engineering, 2007).

Integral approach

Thinking in systems as a whole and throughout the entire life cycle stimulates an integral approach. Integration is about bringing together different aspects to make it a whole (Douglass, 2016). It is important to involve all the disciplines involved in the process throughout the life cycle, so that everything can be tuned to complete a successful project eventually. This integral approach is the most important in the early stages, more profit and benefit can be obtained in these stages because all the different disciplines can be brought together (Boehm, 2012). Integration not only exists between different disciplines, but also within the internal and external environment. This interaction must be managed, monitored and guaranteed continuously as well (Locatelli, 2014).

An integral approach is also related to the other general principles of SE. A single relationship has already been mentioned in a previous section, however the relationships with the other general principles have not yet been appointed. A multidisciplinary approach ensures that all disciplines are involved throughout the whole life cycle, including the stakeholders with their requirements and wishes. Through an integrated approach right from the start of the process, disputes and confrontations are avoided and customer satisfaction is ensured throughout the process (**=customer management**) (Erkul, 2016).

Through the involvement of all relevant disciplines, appropriate project solutions can be identified, even in complex environments. Due to the participation of both engineering and non-engineering disciplines, a balanced system solution can be achieved (**=design flexibility**) (Steiner, 2015).
Lastly, an integrated approach also ensures and guarantees a part of requirements management. Through the continuous interaction and multidisciplinary approach, new or changed requirements are visible and can therefore be better managed (**=requirements management**) (Locatelli, 2014).

Customer management

To manage the customer demands, it is first of all important to determine who the customer is. Seen from the SE theory, the customer is seen as all stakeholders who already have or get a relationship with the system and thus not only the paying customer. All the SE processes should focus on meeting the needs of this customer (Werkgroep Leidraad Systems Engineering, 2009). The customer’s needs are therefore translated into stakeholder requirements (Componation, 2015). Stakeholders are interest groups who actively participated in a project or can be influenced by the impact of a project.

Examples of stakeholders are the community, pressure groups, affected people, end-users, maintainers, suppliers, manufacturers, buyers etc. (Erkul, 2016).

In order to be able to understand a problem and to create a successful system to solve that problem, a stakeholder analysis must be conducted which roughly consists of three steps (Erkul, 2016). First of all, all stakeholders in the entire life cycle and their corresponding requirements and wishes must be identified. Subsequently, the interrelationships between these stakeholders can be analyzed. Lastly, the influences of the relevant stakeholders can be prioritized and weighed, considering the stakeholders' legitimacy, power and urgency. According to this, it is possible to determine which stakeholders are success-critical and possibly have a major impact on the entire project (Boehm, 2012).

Customer management is also related to the other general principles of SE. Most relationships have already been mentioned in previous sections, however the relationship with design flexibility and requirements management have not yet been appointed. The way in which stakeholder requirements are made visible and ultimately specified is of great importance to the design freedom of the final solution. The stakeholder requirements must be accurate statements about what the stakeholder needs **(=design flexibility**) (Douglass, 2016).

The requirements and wishes of stakeholders may vary or change during the life cycle of a project, which can be made clear by customer management (Nahyan, 2014). Therefore, it is important that the stakeholders needs become visible in a transparent process and that they are evaluated by verifying and validating whether the final system meets the stakeholder requirements (**=requirements management**) (Steiner, 2015).

Design flexibility

It is desirable that the client provides design flexibility in the contract specification, to a certain extent, because it stimulates the creativity of the potential contractors (Werkgroep Leidraad Systems Engineering, 2009). Design flexibility can be created due to decomposition and abstraction (Broniatowki, 2017). Decomposition and abstraction influence each other, this will be further described below.

Decomposition is the division of the entire system into smaller sub-systems, these sub-systems can also be decomposed into components, often this is the lowest level in this hierarchical subdivision (Broniatowki, 2017). If necessary, components can also be further decomposed and specified (Steiner, 2015). The decomposition of the system ensures that the systems requirements are easily traceable to all components within the system. Using decomposition, can also lead to a more easily validation of the customer requirements (Steiner, 2015). Thus, decomposing is actually working from rough to fine, or in terms of abstraction, from abstract to specific. Within SE, this top down and bottom up approach is often represented with the aid of the V-model (figure 2.1) (Locatelli, 2014).

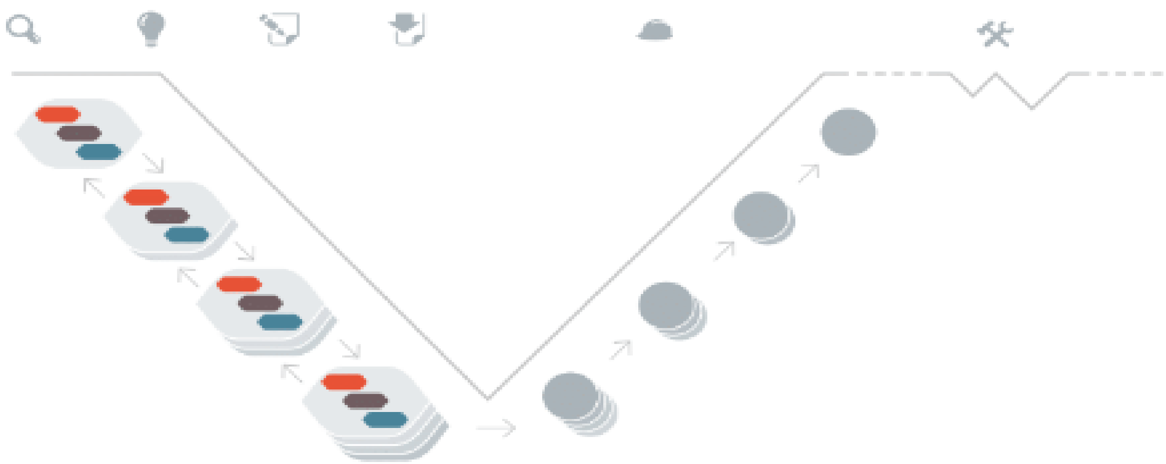


Figure 2.1: V-model (Werkgroep Leidraad Systems Engineering, 2013)

The left hand side of the V-model is elaborated on the basis of the top down approach, using system definition and decomposition to come to a system design. The right hand side of the V-model is elaborated based on the bottom up approach, integration and the application of verification results into system integration (Locatelli, 2014). The process starts with still a very abstract customer demand in the top left corner of the V. Further down on this side, this abstract customer demand is made more specific with the aid of iterative specification and decomposition. During this process, the design is increasingly specified, within the specified solution space, by making design choices. This process has everything to do with abstraction, this process is also called iterative specification and is shown in figure 2.2 below (Broniatowski, 2017).

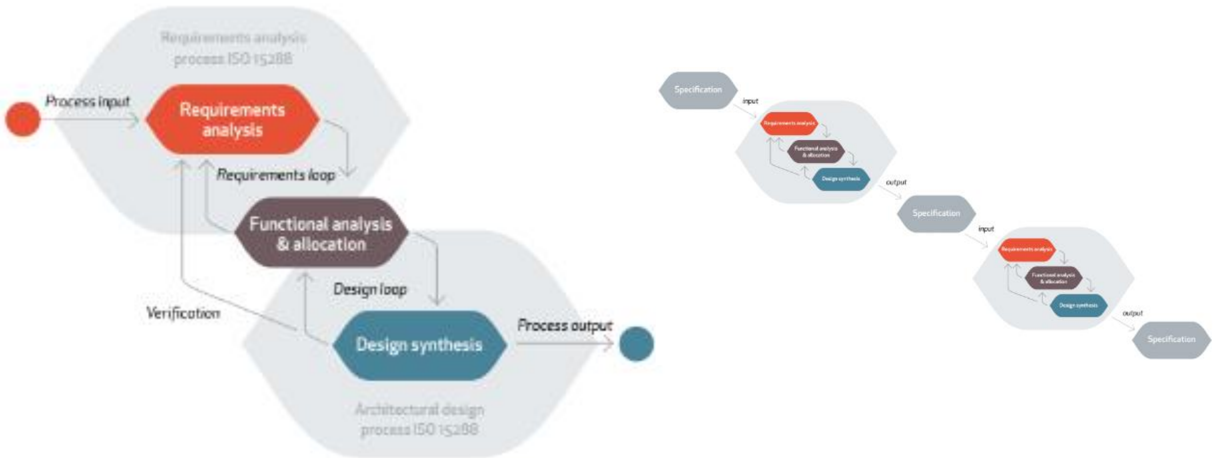


Figure 2.2: Iterative specification (Werkgroep Leidraad Systems Engineering, 2013)

Iterative specifying is a process in which requirements, functions and solutions are developed together (Douglass, 2016). The input for this process are the customer demands, which has laid down requirements and solution space for the system. These requirements are structured, allocated and translated into functional requirements that the system must be able to carry out in order to meet the customer demand. Subsequently, based on these functional requirements, design choices can be made that fit within the solution space and meet the previously established requirements and functions. In their turn, design choices may possibly provide new requirements and functions, which is why it is necessary that the specification process is carried out iteratively. Therefore, the requirements-, design- and verification loop have been added in this process (Werkgroep Leidraad Systems Engineering, 2007). This iterative process of specifying is also carried out at several levels of detail, for each detailing step an increasingly deeper level of detail is achieved, if desired. The V-model is therefore flexible and resistant to changing customer requirements or functions (Douglass, 2016). The final result of the iterative process is a specified system, or in other words, a design that fits within the solution space (Componation, 2015). By applying and going through this process, design choices are made explicit and traceable, as well as the ultimately system meets the customer demand (Werkgroep Leidraad Systems Engineering, 2009).

Design flexibility is also related to the other general principles of SE. Most relationships have already been mentioned in previous sections, however the relationship with requirements management has not yet been appointed. The iterative process already shows the relationship between design flexibility and requirements management very well. The requirements not only form the input for the entire process, but also parts of requirements management can already be recognized in the iterative process of specifying, such as the verification loop (**=requirements management**) (Steiner, 2015).

Requirements management

Requirements management is the SE process to analyze, specify, capture and track requirements (Locatelli, 2014). In order to be able to manage requirements, it is important to know what the aim is of requirements and how these should be specified. According to Wheatcraft (2014) the purpose of requirements is as follows: "communicate clearly the needs of various entities into a formal language such that the intent is readily understood by those whose job it is to implement the requirement, by those responsible for proving the built system meets the requirement and by those responsible for proving the resulting system meets the needs of the relevant entity". The aim of the requirements management process is therefore to translate the customer requirements specification into a measurable system specification, which in its turn need to be translated into the final product, a contract specification of the assignment request for the market (Steiner, 2015).

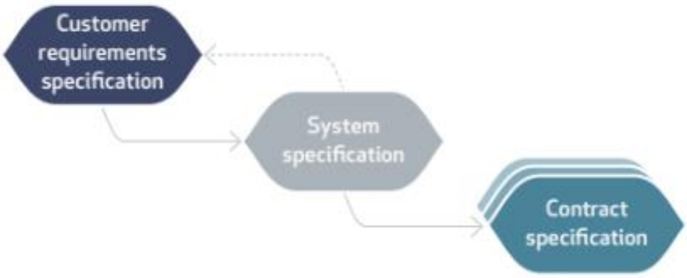


Figure 2.3: Requirements specification process (Werkgroep Leidraad Systems Engineering, 2013)

In order to guarantee this purpose, requirement specifications must meet a certain level of quality. When the quality of requirement specifications increases, the customer satisfaction with the resulting system will also increase (Douglass, 2016). The characteristics for well-formed requirements are as follows;

- SMART (Werkgroep Leidraad Systems Engineering, 2007):
  - Specific (unambiguous, singular, represent a single thought and interpretation, complete) (Boehm, 2012)
  - Measurable (testability, able to verify and validate) (Componation, 2015)
  - Acceptable (Locatelli, 2014)
  - Realistic (feasible within the appropriate constraints)
  - Time-bound (Wheatcraft, 2014)
- Status (accepted or not) (Werkgroep Leidraad Systems Engineering, 2009)
- Appropriate (not more detailed or specific than is necessary) (Douglass, 2016)
- Traceable (allocation to lower and upper requirements and the source) (Steiner, 2015)

As described above, a requirement must be (among other things) measurable, whereby the requirement can be verified and validated. Verification and validation (V&V) is one of the most important principles of SE and have even been processed and recognized in the definition of SE. Verification is a **check if it is done right**, verification has been described in the definition as 'a well-functioning integral system is realized within the stated conditions'. Validation, on the other hand, is a **check if the right thing is done**, validation is included in the definition as 'satisfaction is creating among all involved stakeholders'.

"SE is a systematic and explicit method, which ensures that complex construction and maintenance infrastructure projects are managed effectively and efficiently in a structured and controlled way. Wherein the customer is the key, **satisfaction is created among all the involved stakeholders** and **a well-functioning integral system is realized within the stated conditions**."

Altogether, verification ensures that the system meets the requirements and validation ensures that the system actually meets the customers demand (Douglass, 2016). V&V is conducted at every level of detail and in all phases of the life cycle, not just at the end. Therefore, it is important that criteria are established for V&V (Wheatcraft, 2014); (Department of Defense, 2001):

- Verification level ('what')
    - At what level the stakeholder is satisfied, agreements and criteria about e.g. the lower and upper limit
- Verification assessor ('who')
    - Responsible party, e.g. characteristics or preference of the assessor
- Verification technique ('how')
    - E.g. by means of an analysis, inspection, demonstration, test etc.
- Verification phase ('when')
    - During which life cycle phase
- Verification results ('where')
    - Documentation of the results
- Verification & validation status ('why')
    - Complete or not complete, true or false etc.

2.2 Construction and maintenance projects

Infrastructure construction and maintenance projects have always been two separate processes, but due to the attendance of new integrated contracts and the life cycle approach, also cohesion between both processes will now be visible (Celauro, 2017). For example, the decisions made in the beginning of the construction process, have a major impact on the, subsequent, maintenance process (Lopes, 2016). Also, the aim of both processes is almost the same, namely the implementation of physical infrastructure networks, which are necessary to add, extend (**=construction projects**) or retain, renew or replace (**=maintenance projects**) functionalities and performances (Rijkswaterstaat, 2016). In order to identify these and all other differences between construction and maintenance projects, both processes need to be compared on the basis of the same characteristics.

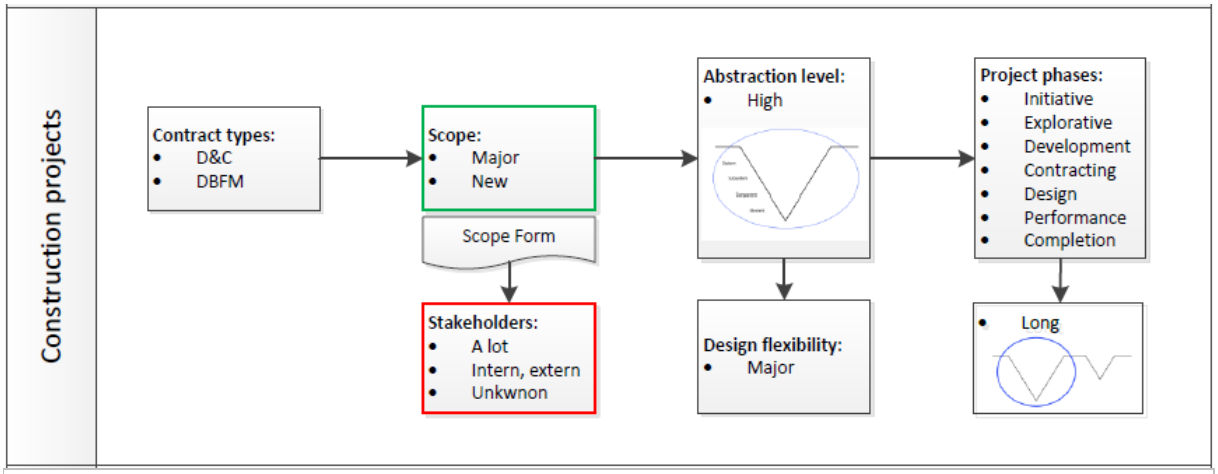
Globally, but also specifically in the Netherlands (Verweij, 2015), major infrastructure projects have been characterized throughout the years by their complexity, long process and life duration, major impact on the economy and the environment, the large number of stakeholders involved and political and public influences (Goodfellow, 2014). These characteristics have major impact on the results of these major infrastructure projects, two-thirds of these projects are related to cost overruns, time delays and the failure to deliver benefits and fulfill promises (Brunet, 2016).
These characteristics are found and selected by analyzing the main characteristics of major infrastructure projects and it has been checked whether these characteristics are relevant or are somewhat related to SE. Major infrastructure projects, as mentioned earlier, are mainly known for their complexity, cost and time overruns. This complexity is caused, among other things, by the **scope** of the project and the associated number of **stakeholders** (Celauro, 2017). To make it even more complex; various **contract types** are available to manage these complex projects and processes as effectively and efficiently as possible (Eriksson, 2017). The selected contract type, but also the established scope of the project, creating both already several requirements (Mirza, 2013). As a result, the **abstraction level** of specifying and thus also the **design flexibility** is therefore already partially influenced and determined (Verweij, 2015). Independent of the selected contract type, on a global level the same activities are carried within the construction and maintenance projects, such as the process of formulating the request for the market until the transmission and evaluation of the project. The final characteristic of large infrastructure projects is therefore going through all the **project phases** (Rijkswaterstaat, 2016).

Altogether, all these characteristics are influencing and related to each other. On the basis of these interrelationships, the construction and maintenance projects will therefore be compared on the following characteristics:

- Contract types; think of different forms and integrated contracts
- Scope; think of the size and condition of the scope and the assignment formulation
- Stakeholders; think of the amount, involvement and knowability of the stakeholders
- Abstraction level; think of a high or low level of abstraction
- Design flexibility; think of a large or limited degree of freedom
- Project phases; think of the different processes and activities in projects

2.2.1 Construction projects

On the basis of the six characteristics of major infrastructure projects mentioned before, the construction process will be analyzed. Figure 2.4 shows how content has been given to these characteristics within construction projects, the figure will also be explained textually.



Legend

Characteristics of maintenance projects
This characteristic forms a risk
This characteristic forms not a risk, but forms certainty
➔ Influence and connection between characteristics

This figure shows how the six selected characteristics of infrastructure projects are interconnected and influence each other in construction projects. Mostly and usually, selecting a suitable contract type is the first step in a project and therefore has a major influence on the further project and process. The selected contract type influences and is related to the scope of a project, the scope of a project influences in its turn the stakeholders of a project (a large scope often causes many involved stakeholders) and also influences the abstraction level of specification (a new scope often causes a high level of abstraction). The abstraction level of a project not only influences the project phases and associated activities which should be completed, but also relates to the design flexibility in the project (a high level of abstraction often causes major design flexibility).

Figure 2.4: Construction projects characteristics

Integrated contracts are increasingly used, also in the Netherlands (Lenferink, 2013). The two most used and best-known contracts types are the Design & Construct (D&C) and the Design, Build, Finance and Maintain (DBFM) contract. In both **contract types**, the contractor is responsible for several, integrated tasks, such as the design and construction of a project. Due to these contract types, flexibility is created for the contractor, to come to an appropriate and innovative solution. This is possible because only the desired output of the request has been described, in contrast to an already detailed and almost elaborated design (Nyström, 2016).

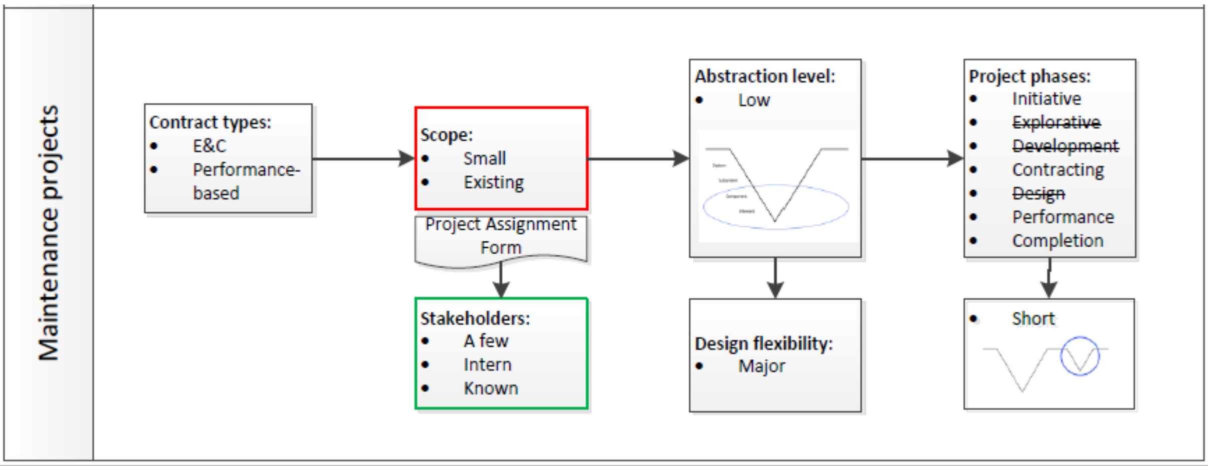
The type of contract determines the **scope** of the project. In general, the scope of construction can be described as major and new, which ensures clarity and therefore no risks (Grimsey, 2002). The scope, in its turn, is determined by the quantity and type of stakeholders, the scope and stakeholders of a project are therefore intertwined (Fageha, 2013). Due to the major size and novelty of the scope within construction projects, also many **stakeholders** are involved in the process. Not only internal but also external stakeholders are important to involve, which creates an even greater number of stakeholders and interrelationships that have to be taken into account (Eriksson, 2017). It is also characteristic of the construction process that not all stakeholders are known or made clear and insightful, this is because it concerns a major and new environment with various stakeholders, which in its turn is a major risk in construction projects (Fageha, 2013).

The defined contract type and scope (interrelated with the stakeholders involved), influence the **abstraction level** of specification and therefore also the **design flexibility**. Because the project is major and new, only the desired and required output of the project need to be specified, the entire design process has to be go through from the highest level of abstraction and this creates in its turn major design flexibility and freedom for specifying and designing suitable and innovative solutions (Lenferink, 2013).

Going through all **project phases** is generally an obviously, initially blank and long process in the case of construction projects (Locatelli, 2017).

2.2.2 Maintenance projects

Also the maintenance process will be analyzed on the basis of the six selected characteristics of major infrastructure projects. Figure 2.5 shows how content has been given to these characteristics within maintenance projects, the figure will be explained textually as well.



Legend

- Characteristics of maintenance projects
- This characteristic forms a risk
- This characteristic forms not a risk, but forms certainty
- ➔ Influence and connection between characteristics

This figure shows how the six selected characteristics of infrastructure projects are interconnected and influence each other in maintenance projects. Mostly and usually, selecting a suitable contract type is the first step in a project and therefore has a major influence on the further project and process. The selected contract type influences and is related to the scope of a project, the scope of a project influences in its turn the stakeholders of a project (a small scope often causes a few involved stakeholders) and also influences the abstraction level of specification (an existing scope often causes a low level of abstraction). The abstraction level of a project not only influences the project phases and associated activities which should be completed, but also relates to the design flexibility in the project (a low level of abstraction often causes limited design flexibility).

Figure 2.5: Maintenance projects characteristics

Integrated contracts were developed and used for the first time in maintenance projects. It started with the Engineering & Construct (E&C) contract, the contractor is responsible for bringing order and functioning of the existing infrastructure, this is the so-called variable maintenance (Lopes, 2016). Another common **contract type** is a performance-based contract, within this contract type the contractor is responsible for the multiannual maintenance of existing infrastructure, this is the so-called long-term condition-based maintenance (Xiang, 2017). Both contract types have a specific and detailed legal character, due to this the request for the project assignment is already very technical specified and the design has already been largely elaborated (Lenferink, 2013).

An over-specified project assignment is often created by the **scope** of a project, because the scope concerns an already consisting system, this forms a major risk in of maintenance projects because this often means that a lot of information is missing or even unknown. Because the scope is limited to the already existing project, the scope is in addition to construction projects relatively small (Eriksson, 2017). Because the scope and **stakeholders** are intertwined, the already existing and small scope also affects the quantity and type of stakeholders within maintenance projects. Maintenance projects especially take place within their own and existing area, this ensures that known, internal and less stakeholders are involved in this process, which ensures clarity and therefore no risks. Because the environment generally does not experience disturbances, external stakeholders are often not involved in maintenance projects. Yet, if disturbance can be experienced nevertheless, then the relevant external stakeholders are often already secured within the internal process (Locatelli, 2017).

Due to the often over-specified project assignment and the already existing and small scope, the space for innovative designs and design flexibility is very limited (Nyström, 2016). The **abstraction level** of specification of the design is, because of the above-mentioned, at a low and specific level with limited **design flexibility** (Lenferink, 2013).

In the case of maintenance projects, going through all project phases is not self-evident and more complicated than construction projects, because the process does not start blank. Often, historical data or current information is limited available or even lost. With the help of asset management this should be solved or even prevented. However, in practice it appears that these asset management principles are often lacking in maintenance projects, which results in that not all processes can be completed again or further can be go through in a complete and proper way (Shah, 2017). It is found very important that asset management should be improved in maintenance projects to tackle these problems and to be able to go through all **project phases**. Also, often there is the assumption that the design process does not apply in maintenance projects and therefore cannot be completed. However, as a matter of fact, design choices are made, only at a much lower level of abstraction and with limited design flexibility. Thus, this does not mean that there is no design process in maintenance project (Shah, 2017).

2.2.3 Differences

First all the characteristics of construction and maintenance projects have been separately described, subsequently the differences between both processes can be made insightful and be analyzed. In table 2.1 the differences between construction and maintenance projects are clearly arranged, shown and further explained below.

The first difference is immediately visible, these are the different types of **contract types**. The type of contract forms the basis for the further process, it is therefore necessary that the contract type is explicitly connected to construction activities or maintenance activities. Contracts need to fit seamlessly with the type of project, hence specific and different contract types are applicable for construction or maintenance projects. Therefore, the difference in contract types cannot be reduced or removed and is thus important to be aware of.

Another major difference can be seen in the **scope** of the projects. In contrast to maintenance projects where the scope is small and already existing, the scope of construction projects is major and new. An important difference is that the scope in maintenance projects often forms a major risk because often the current condition of the project is unknown, while in construction projects the scope is a certainty instead of a risk. With the aid of the scope, the nature, size and limitations of a project are indicated, therefore the scope is very specific for construction or maintenance projects. Therefore, the difference in scope cannot be reduced or removed and is thus important to be aware of.

The various scopes also affect the differences between the **stakeholders**, because scope and stakeholders are interrelated. In construction projects, many stakeholders, internal and external, are involved in the process. Most of the stakeholders are still unknown, this is due to the novelty and major size of the scope, this forms a major risk in construction projects. While in maintenance projects the stakeholders are generally known, due to the already existing and small scope. As a result, fewer, only internal, stakeholders are involved in this process. Despite the differences in amount, involvement and type of stakeholders, both construction projects as well as maintenance projects have to do and work with stakeholders.

Table 2.1: Differences between construction and maintenance projects

Characteristics	Construction projects	Maintenance projects
Contract types	D&C contract DBFM contract	E&C contract Performance-based contract
Scope	Major New	Small Existing
Stakeholders	A lot Intern, extern Unknown	A few Intern Known
Abstraction level	High	Low
Design flexibility	Major	Limited
Project phases	Initiative Explorative Development Contracting Design Performance Completion	Initiative ~~Explorative~~ ~~Development~~ Contracting ~~Design~~ Performance Completion

Construction projects are specified from the highest, system, level down to the lowest, element, level. However, maintenance projects are not specified from the highest system level, because the system already exists. The maintenance design activities mainly take place at a lower **abstraction level**, usually at component or element level. As a result, the **design flexibility** is also small and limited, in contrary to construction projects where the design flexibility is major. But, despite this difference in abstraction level and design flexibility, the actual activities of specifying are to a certain level very similar and remain more or less the same. Whether it concerns the specification of a river connection in a construction project (system level) or the specification of a new highway coating in a maintenance project (component level), in both examples design choices need to be made, regardless of the level of abstraction and design flexibility.

The assumption exists that certain **project phases** can or should not be completed during maintenance projects. As explained earlier, in maintenance projects the design process is completed as well but at a lower abstraction level, thus this does not mean that the process can or should be skipped. However, this does show that in maintenance projects probably the project phases are shorter and can be carried out faster, in comparison with construction projects. This can also be seen with the aid of the V-model in figures 2.4 and 2.5, the first major V indicates the construction process and takes a long time. The second, smaller, V indicates the maintenance process and can be completed more quickly. However, both processes, construction as well as maintenance, can and must go through all project phases.

2.3 Sub conclusion

The literature study has provided insight into the background and general principles of SE and into the characteristics and differences between construction and maintenance projects.

One of the most **important** finding from this chapter is the redefined definition of SE. In literature, many different interpretations of the definition of SE arose in the course of time and are not always applicable to infrastructure projects, therefore it was difficult to provide an single definition. In order to create clarity and unambiguity, a renewed definition of SE is created. This definition therefore forms the base for this research. The definition is as follows:

"SE is an systematic and explicit method, which ensures that complex construction and maintenance infrastructure projects are managed effectively and efficiently in a structured and controlled way. Wherein the customer is the key (3) (*customer management*), satisfaction is created among all the involved stakeholders (4) (*design flexibility*) and a well-functioning integral (2) (*integral approach*) system (1) (*systems thinking*) is realized within the stated conditions (5) (*requirements management*)."

In this definition of SE, a link has been made to the most **interesting** finding in this chapter, namely the five general principles for successful SE. All these principles are equally important and are related to each other. The five general principles of SE are as follows:

1. Systems thinking
2. Integral approach
3. Customer management
4. Design flexibility
5. Requirements management

Some of these SE principles correspond to the most important characteristics of major infrastructure projects, for example the design flexibility and the connection between customer management (SE) and stakeholders (infrastructure characteristics). These characteristics of construction and maintenance projects are as follows:

- Contract types
- Scope
- Stakeholders
- Abstraction level
- Design flexibility
- Project phases

One of the most **remarkable** findings has everything to do with these characteristics. Based on these characteristics, construction and maintenance projects have been compared. It was expected that the differences between these two processes would be major, but above expectations some differences are not even so different up to a certain level. Despite the identified differences in all characteristics, construction and maintenance projects both roughly go through the same project phases and associated activities, this, as well as the design process and activities of specifying, are to a certain level very similar and remain largely the same.

3. Current practice

In order to translate theory into practice, this chapter links the findings of the conducted literature study with the application of SE within Rijkswaterstaat. This chapter describes the way in which SE is applied and identifies bottlenecks of its application in maintenance projects of Rijkswaterstaat.

3.1. SE within Rijkswaterstaat

The literature study has shown that the application of five general principles can ensure successful SE. These five general principles are: **systems thinking**, **customer management**, **integral approach**, **design flexibility** and **requirements management**. However, this research is conducted in collaboration with Rijkswaterstaat, which means that various products, processes, working methods and case studies from Rijkswaterstaat need to be analyzed and used. In order to make the translation from theory to practice, a link will be made from the literature study into the actual application of SE within Rijkswaterstaat.

As previously mentioned, Rijkswaterstaat is one of the largest infrastructure clients of the Netherlands and are specialized and leading in the field of SE (Rijkswaterstaat, 2017). Since 2007, Rijkswaterstaat makes great strides with the introduction and implementation of SE, for example Rijkswaterstaat was one of the four initiators to create a guideline for SE in the civil engineering sector. The first version of this guideline for SE mainly was an introduction and explanation of the theory of SE (Werkgroep Leidraad Systems Engineering, 2007). A second version of the guideline appeared two years later in 2009, the theory from the first guideline was made practical for application and control of the SE techniques (Werkgroep Leidraad Systems Engineering, 2009). The, up to now, final guide, version 3, was drafted in 2013 and discusses the experiences and problems of the recent years, the current situation and the goals and challenges for the future. All of this is viewed and discussed at three different levels, namely the sector-, organizational and project level (Werkgroep Leidraad Systems Engineering, 2013).

As a result of these SE guidelines, Rijkswaterstaat has developed its own E-learning. This E-learning deals with the basic principles of SE and is applicable to both construction and maintenance projects within Rijkswaterstaat (Rijkswaterstaat, 2017). Both the guideline SE and the E-learning show that Rijkswaterstaat, just as the literature study, also applies five general principles for successful SE, these are as follows (Rijkswaterstaat, 2017):

1. **Systems thinking**
2. **Customer needs**
3. **Optimization life cycle**
4. **From abstract to specific**
5. **Explicit working**

By concisely analyzing these principles one by one, not only the interpretations behind these principles become clear, but perhaps also a possible relationship or similarity with the general SE principles from the literature study.

First of all the principle of **systems thinking**, a system is a collection of elements that are interconnected and function together as a whole. Thinking in systems ensures that all the system elements better connect to each other, but also that the system as a whole fits in well with the environment (Rijkswaterstaat, 2017). The concept of systems thinking fits in seamlessly with the same general principle of **systems thinking** from literature, not only the definition but also the reasoning and application correspond.

Then, the following general principle is analyzed, namely **customer needs**. The idea behind this principle is to focus on the customer demand. The customer refers not only to the end user of the system, but also to all the other stakeholders (Werkgroep Leidraad Systems Engineering, 2017). The needs, wishes and requirements of all these stakeholders need to be retrieved and recorded, in order to create a suitable solution that meets all the specified customer requirements. The aim and associated activities of this general principle, again, correspond to one of the general principles of SE from the literature study, namely **customer management**.

The third general principle focuses on **life cycle optimization**. This means that a system need to cover all phases of the life cycle, phase transcendental thinking is necessary. It is important that the relationship between the processes is seen and that from now on the different projects and associated teams work integrally. An example can clearly show the importance of this; during the construction process investments can be made in more sustainable materials, this is more expensive than normal. However, during the maintenance process these durable materials will require less maintenance than normal, which causes that the costs over the entire life cycle will be lower than normal (Werkgroep Leidraad Systems Engineering, 2013). Again, all of the above corresponds to one of the general principles from the literature; **integral approach**. From the viewpoint of an integral approach, it is found to be important to involve all the disciplines involved in the process throughout the entire life cycle, which therefore indeed corresponds to the principle of life cycle optimization.

From abstract to specific, which is the fourth general principle of SE within Rijkswaterstaat. Working from abstract to specific can be clearly explained with the aid of the V-model. The V starts with abstract customer requirements, these requirements need to be translated into functions, which in its turn need to fulfill the customer requirements. By thinking in terms of functions and not in designs or solutions, **design flexibility** is created (Rijkswaterstaat, 2017). The literature on this general principle, design flexibility, also refers to the V-model to stimulate working from rough to fine. Therefore, again, the general principles from theory and in practice correspond.

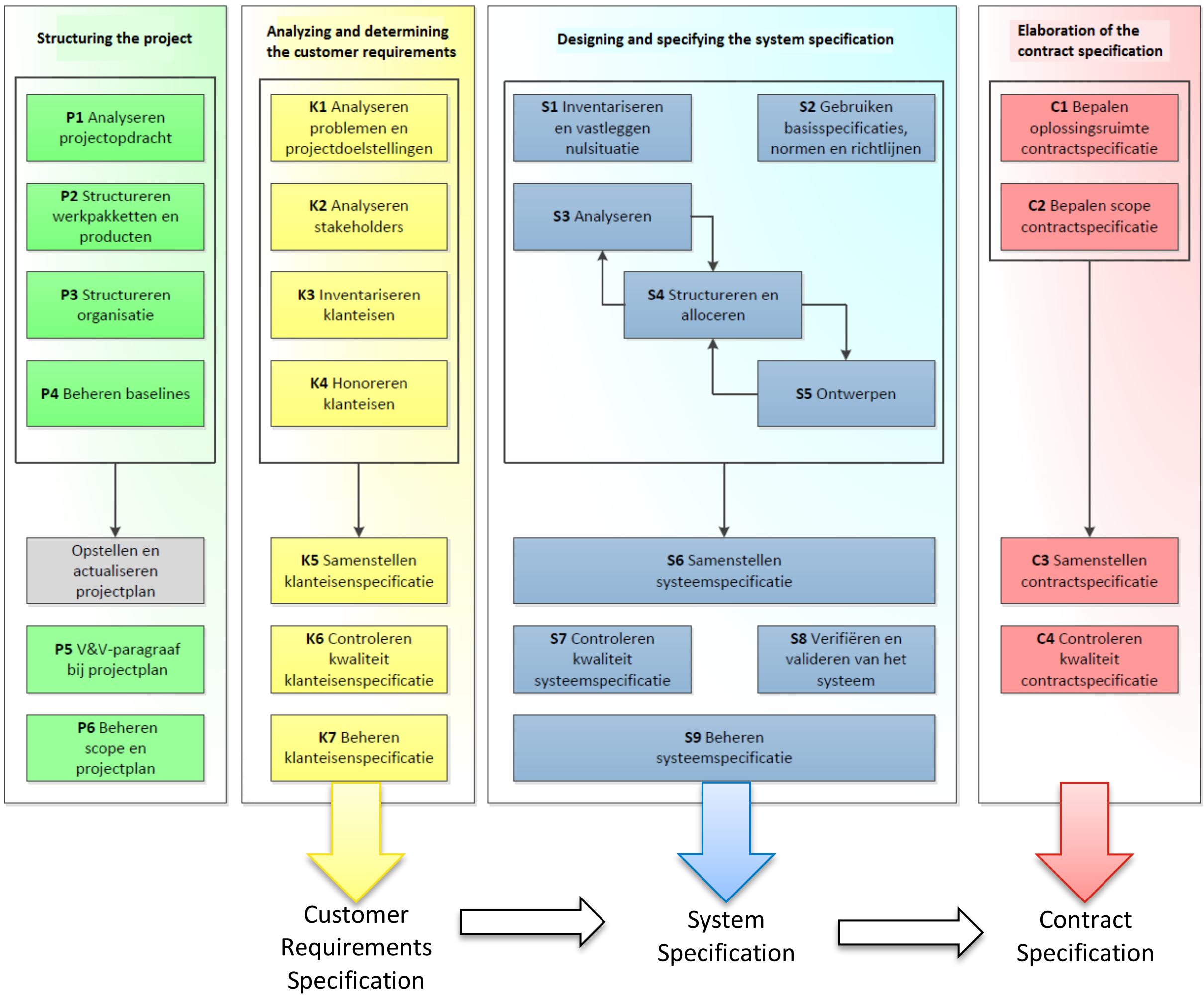
The last general principle is **explicit working**. Working explicitly means that all information, e.g. requirements and design choices, need to be recorded and be always accessible, traceable and transferable (Werkgroep Leidraad Systems Engineering, 2013). A supporting process for explicit working is V&V. V&V must be carried out during each phase of the life cycle. All information, design choices and final solutions must be verified and validated against the requirements. This process can also be seen as **requirements management**.

Altogether, the five general principles of SE as a result of the literature study, fit in seamlessly with the five general principles of SE that are applied in practice within Rijkswaterstaat.

3.2. Process description SE of Rijkswaterstaat

Rijkswaterstaat has translated these five general principles of SE into a process description. This process description describes, in a clear and unambiguous way, the application of SE for projects within Rijkswaterstaat (Rijkswaterstaat, 2017). With projects within Rijkswaterstaat the projects within the primary process of construction and maintenance are meant. The process description SE is designed in such a way that it is (in principle) applicable to every project environment, project situation and project phase. From plan development up to and including the contract preparation, that is the scope in which the process description SE is applicable. Therefore, the input for this process is the project assignment and the contract specification (for outsourcing the project to a contractor from the market) is the desired output of the process description SE.

When the process description SE is analyzed (figure 3.1), in a glance can be seen that it consists of four main processes: structuring the project, analyzing and determining the customer requirements, designing and specifying the system specification and finally the elaboration of the contract specification. Each of these main processes consists of different process steps, these are not the only steps required in order to achieve a contract specification, but these are the steps that are only related to the field of SE. The relationship between these process steps and the main processes is important and becomes visible through the three different specifications, which are established during these processes and are also interrelated to each other. These three specifications are the customer requirements specification, system specification and contract specification. The customer requirements specification is the output and the result of the second main process: analyzing and determining the customer requirements. As the name already suggest, all (honored) customer requirements are included in the customer requirements specification. The output of the second main process, the customer requirements specification, forms in its turn the input for the third main process; designing and specifying the system specification. The customer requirements are translated into system requirements during this process, all these system requirements together form the system specification. The system specification is therefore the output of the third main process and also the input for the subsequent process, namely the fourth and final main process; the elaboration of the contract specification. The system requirements are translated into contract requirements during this process, these contract requirements together form the contract specification. The contract specification is the output of this last main process, but also the desired output of the entire process of the process description SE (Rijkswaterstaat, 2017). Because these three specifications are very important, they are added in figure 3.1 and therefore also visualize the above explanation.



Legend

- Process steps within the main process ‘structuring the project’
- Process steps within the main process ‘analyzing and determining the customer requirements
- Process steps within the main process ‘designing and specifying the system specification’
- Process steps within the main process ‘elaboration of the contract specification’
- Clustering of process steps
- ➔ Forms the input for the following process steps

In this figure the process description SE for Rijkswaterstaat projects is presented. The process description consists of four main processes, namely structuring the project, analyzing and determining the customer requirements, designing and specifying the system specification and elaborating the contract specification. These four main processes each exists in its turn of various process steps. Also, the three specification products, which are developed with the aid of the process description, are shown in this figure. In this way it becomes clear during which main process which specification is being developed.

Figure 3.1: Process description SE for Rijkswaterstaat projects (Rijkswaterstaat, 2016)

Now that the interrelationships between these three important specifications are made visible, it is easier to understand that is it important that all specifications are managed during the entire process. For example, if a new or changed customer requirement occurs, the customer requirements change which in its turn creates a new version of the customer requirements specification. This new customer requirements specification influences in its turn the system specification and the final important contract specification. Thus, this example shows that everything in the process description is coherent and influences each other, therefore this process has to be carried out iteratively and continuously be managed (Rijkswaterstaat, 2017).

The layout of the process steps in the process description is all the same, consisting of the goal, required input, activities to be performed and the desired output per process step. Also is for each process step indicated which role from the IPM-team (integral project management team) is primarily responsible for the relevant process step. The roles within such IPM-teams always consist of five managers: the project manager, technical manager, environmental manager, contract manager and the management project manager. Furthermore, the specific content per process step will not be discussed here, among other things because the process description including content can simply be found and is freely accessible to everyone (Rijkswaterstaat, 2017).

3.3. Bottlenecks SE in maintenance projects

Although Rijkswaterstaat claims that the process description SE is applicable to every project environment, project situation and project phase (Rijkswaterstaat, 2017), in practice it has unfortunately been proven to be the contrary. The process description is initially developed for construction projects and therefore not entirely applicable for maintenance projects. The objective of this research is to improve the application of SE in major infrastructure maintenance projects, in order to achieve this objective already some general differences between construction and maintenance projects have already been identified. But also the bottlenecks within the specific process description SE need to be identified and analyzed, so that eventually these bottlenecks can be solved later on in this research.

The bottlenecks of the application of SE in maintenance projects have been identified with the aid of a case study and conducting interviews. The selected case study is a major maintenance project from the production line B and the interviews were conducted with all the five managers within the IPM-team of this case study project (more detailed information about the substantiation, choice and execution of this data collection can be found in paragraph 4.2). The conducted interviews have been worked and typed out and can be found in the appendix (I till IV).

Out of the analysis of the case study and the conducted interviews, various bottlenecks have been identified. These bottlenecks are divided into two categories, namely bottlenecks that relate to the application of SE to both construction and maintenance projects (so, bottlenecks in the process description in general) and bottlenecks that relate to the application of SE in maintenance projects in particular.

Bottlenecks in **construction and maintenance projects**, in **general**:

- **Bureaucracy**
  With regard to the activities per process step. This is because it is described too extensively and this causes too large and detailed pieces of text. According to the interviewees the described activities are perceived as unnecessary because it can be assumed that they have sufficient experience, knowledge and professionalism themselves, to give the right interpretation with their expertise to these activities.
- **Verification & Validation**
  There is a lot of ambiguity and lack of clarity about V&V in general. It is still unknown what both terms actually mean and contain and how both terms need to be interpreted.

- **Three specifications**
  A lot of uncertainty is about the different specifications, namely the customer requirements specification, systems specification and contract specification. Unknown is what the precise definitions, goals and differences are between these three specifications. The added value of each specification is also unclear.
- **'Checking' process steps**
  The process steps related to checking the quality of the customer requirements specification (process step K6) and system specification (process step S7) are found to be redundant, not only by the IPM-team itself but also by the customers. The IPM-team finds it redundant because the quality of the specifications is already secured in the fore- and underlying process steps, actually during the entire iterative process. Also the customers find it unnecessary because this simply takes a lot of effort and time.
- **General design of the process description**
  Some bottlenecks are also experienced with regard to the design of the process description. The process description is now often seen and used as a roadmap, through the separate colors, frames and numbered process steps. While in the opinion of the IPM-team this process is actually all related and cannot be followed in a subsequent, step-by-step, way.

Bottlenecks in **maintenance projects**, in **particular**:

- **Bureaucracy**
  With regard to some products or processes in relation to maintenance projects. Maintenance projects differ in some respects a lot with construction projects (chapter 2.2.3), in some of the process steps this difference is very visible and it is not necessary in the case of maintenance projects to make certain products or to go through some processes, because this simply costs too much work and time and actually has little or even no added value.
- **Terminology**
  Much confusion arises due to the terminology used in the process description. All these terms and definitions are focused and based on construction projects, however different terms are used in maintenance projects, which causes confusion and difficulty to understand and apply, while it often involves the same things.
- **Role division of the IPM-team**
  Bottlenecks are experienced with the assigned responsible IPM-role per process step. For some process steps, other responsible roles have been designated (process steps K1, K7, C3 and C4) which fits better during maintenance projects.
- **Internal and external stakeholders**
  When the process description is applied in maintenance projects, many bottlenecks are caused by the stakeholders involved. The process description is adapted for both internal and external and a large number of stakeholders, while in maintenance projects the number of stakeholders is significantly less and usually only internal stakeholders are involved, as the literature study has already shown. This ensures that the process description does not fit well with the involved stakeholders in maintenance projects and many activities do not connect, are unnecessary or provide bureaucracy.
- **V&V paragraph**
  Completely unclear is how the V&V paragraph in maintenance projects should be interpreted (process step P5). It is unknown what exactly should be included in this section and which principles of V&V are applicable in maintenance projects, think of aspects such as responsibilities and abstraction level, which are different in maintenance projects in relation to construction projects as has already been mentioned in the literature study.

- **V&V concerning the customer**
  Some bottlenecks have also been identified within the process step K3. All customer requirements have to be verified and validated during the entire life cycle, in order to do this, agreements must be made with the customer about how, during and later in the process, it can be proven that the customer requirements are actually met and the customer is satisfied. Therefore, agreements must be made about, among other things, the verification method and associated evaluators, as has already been mentioned in the literature study. Currently, these agreements with the customer are not made. First of all, this lack comes from the IPM-team that often does not name or ask anything to the customer about these V&V agreements that should be made, but this lack also comes from the customer itself. The customer often thinks that they do not have any knowledge of V&V, therefore they do not give substance to the agreements about V&V that have to be made.
- **V&V concerning the system**
  Verifying and validating the system is a major bottleneck within maintenance projects (process step S8). First of all, this is caused due to the lack of general knowledge about V&V, just as in the two previous bottlenecks. However, this bottleneck has also arisen due to the aforementioned bottlenecks, namely the drafting of the V&V paragraph (process step P5) and identifying the customer requirements (process step K3). These two bottlenecks are related to the V&V of the system requirements, therefore these three process steps are interrelated and have influence on each other. Verification and validation of the system requirements is not possible if no general agreements have been made about verifying and validating within a project. Even more difficult is to determine whether the customer is satisfied with the system, when in advance no agreements where made with the customer about when the customer is satisfied…
- **Design process step**
  The last bottleneck has to do with designing the system (process step S5). Within the IPM-team there is the illusion that they do not design anything and therefore have nothing to do with making design choices in maintenance projects, because it is already an existing project and therefore an existing design. However, in contrary to the illusion of the IPM-team, design choices are actually made, as has already been mentioned in the literature study. The difference is in the abstraction level, the design choices are made but at a lower abstraction level in maintenance projects than construction projects (do not think of a design choice with regard to a river crossing (tunnel or bridge) in a construction project, but think about a design choice with respect to the type of asphalt in maintenance projects). Due to the low abstraction level, design choices are not recognized within the IPM-team. As a result of which this process step cannot be carried out by the IPM-team, while it has to be carried out, this causes a major bottleneck in this process step and has consequences on the entire process.

Many of the bottlenecks identified and appointed above, are bottlenecks that cannot be specifically attributed to a specific process step, but these are bottlenecks that apply and come back through the entire process description. However, some bottlenecks, especially the bottlenecks that occur in maintenance projects in specific, can directly be assigned to specific process steps. Because these bottlenecks are so specifically attributable, especially compared to the other more general bottlenecks, it appears that these bottlenecks, experienced and frequently mentioned by the IPM-team, are found to be the largest and most important bottlenecks. Therefore, these bottlenecks are mapped in the process description to provide a clear overview (figure 3.2). In the figure the relationship between the three bottlenecks regarding V&V can equally and clearly be seen (P5, K3 and S8), also the bottlenecks in the process steps with regard to analyzing stakeholders (K2) and designing (S8) are also clearly mapped out.

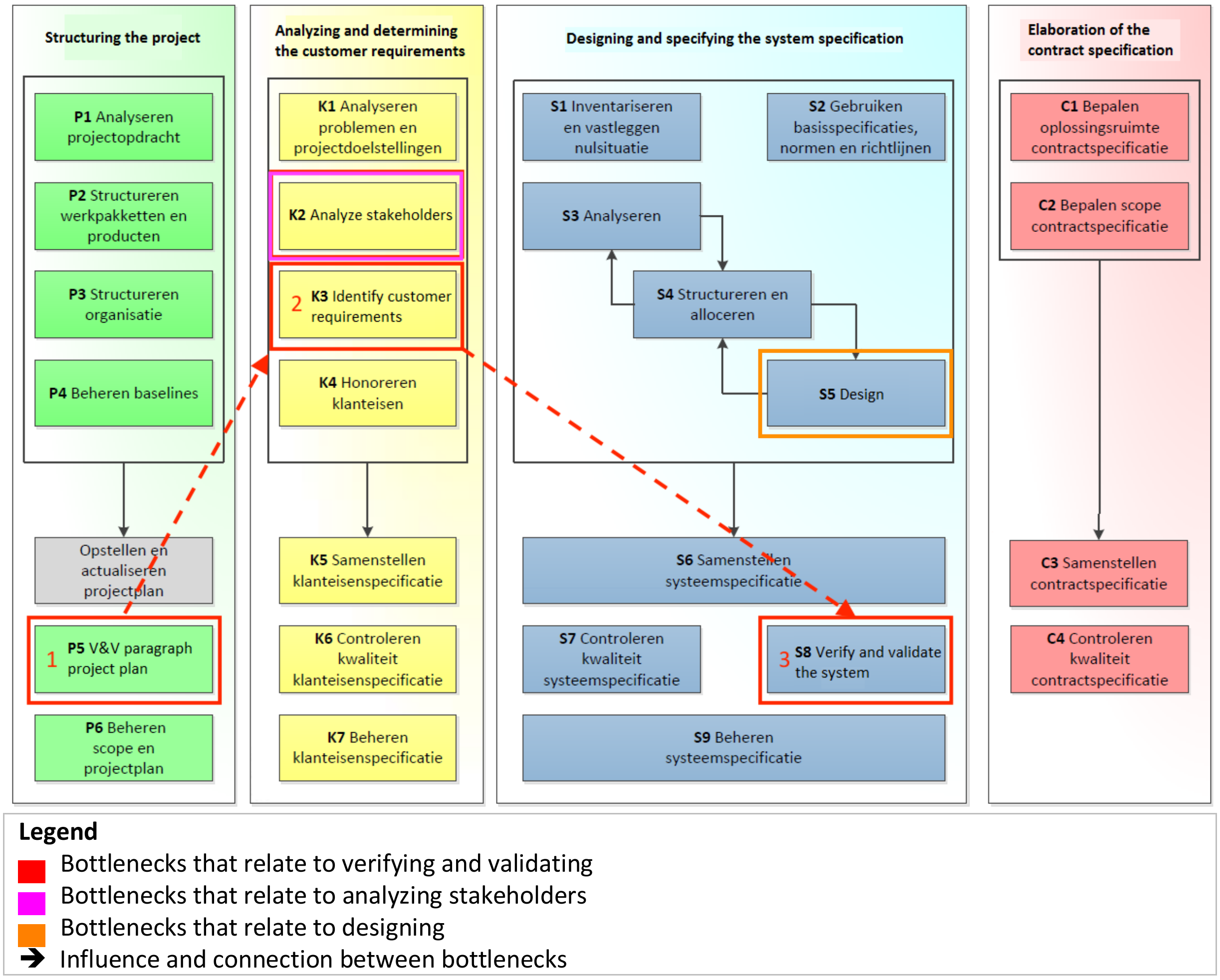


Figure 3.2: Mapped bottlenecks in maintenance projects

All the aforementioned bottlenecks have thus been identified with the aid of the case study (project assignment 2018) and the conducted interviews with the IPM-team of this maintenance project from the production line B. However, it is important that these bottlenecks are verified in the SE work field, not only because SE is their expertise and they have drawn up and continue manage the process description SE, but also from the point of view of Maslow's four learning phases. The four phases are as follows: phase 1 unconsciously incompetent, phase 2 consciously incompetent, phase 3 consciously competent and phase 4 unconsciously competent (NLP-Groningen, 2017). This theory of Maslow describes the different phases in a learning process, in this case the learning process of the IPM-team members of the implementation of SE in their maintenance project. The phase in which the IPM-team belongs can differ per IPM-roll holder and per process step and is therefore difficult to determine. Therefore, it is very important that these identified bottlenecks are verified within the SE field. This can prevent, for example, that important bottlenecks are not being appointed by the IPM-team due to their unconscious incompetency or even that bottlenecks that are mentioned are not really bottlenecks, but are only experienced by the IPM-team their selves.

After the verification session with the entire SE work field, it appeared that they also recognize all the bottlenecks, identified by the IPM-team, and have acknowledged that they often encounter these bottlenecks in practice. Mainly the bottlenecks that have been specifically mapped, in figure 3.2, are considered as very important and most common ones, these bottlenecks therefore have priority. However, one addition came forward during the verification session: a link was found between the process step designing (S8) and the process steps analyzing the project assignment (P1) and managing the scope and the project plan (P6). Designing is largely dependent on how the project assignment and associated measures are formulated and how the final scope and project plan are worked out, demarcated and contracted. Often during the analysis of the project assignment, the design freedom is already limited due to the prescribed measures and it is not yet known to what extent there is damage, for example whether this is only visual or even constructive damage. The IPM-team need to further investigate this during the process and this has a major influence on the design process and the associated abstraction level of the design. All in all, this last important discovered relationship is now also identified and is shown in figure 3.3 below.

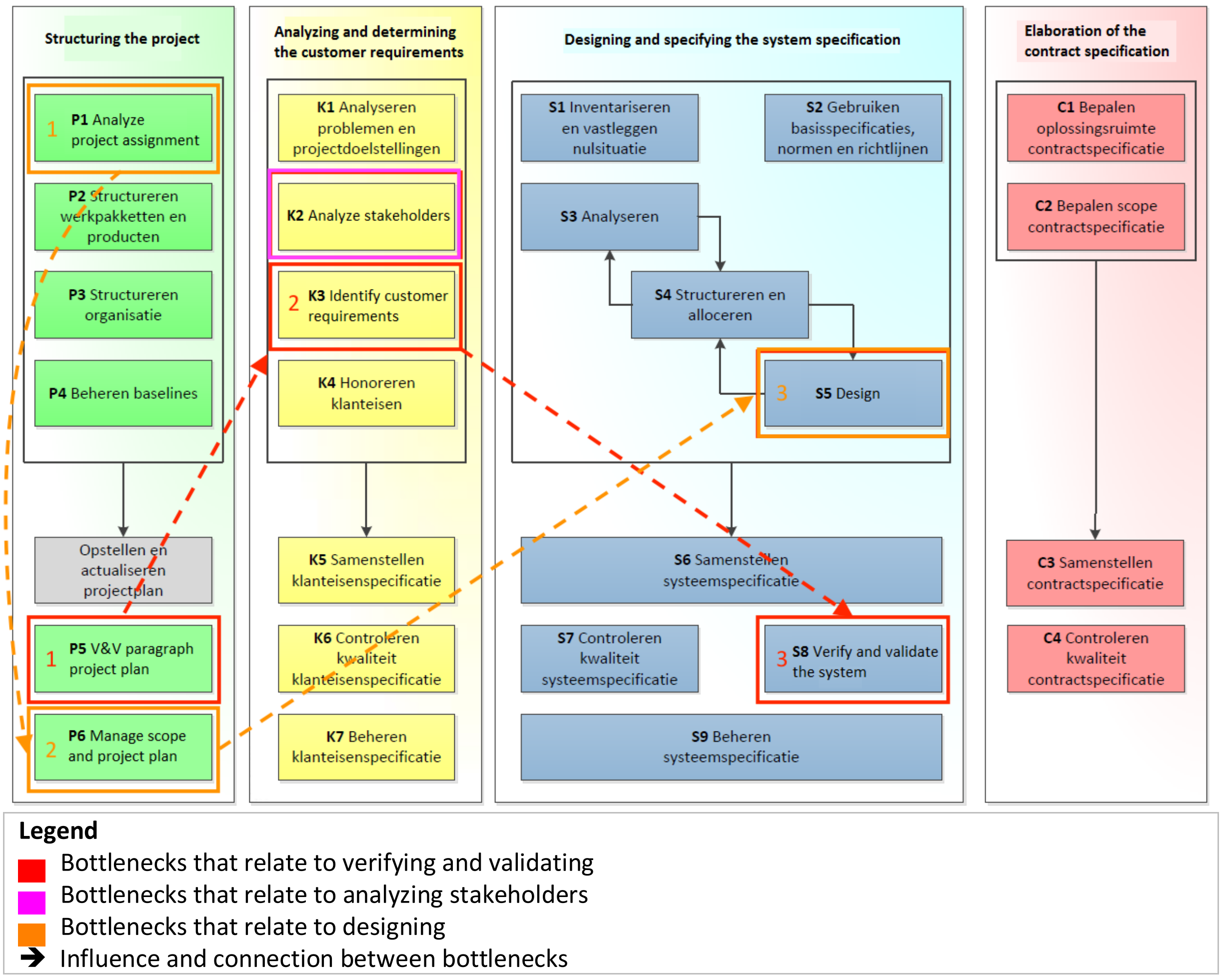


Figure 3.3: Verified bottlenecks in maintenance projects

3.4. Sub conclusion

This chapter has translated the theory of SE from the literature study into practice, namely the actual application of SE within Rijkswaterstaat. This translation was necessary because this research is conducted in collaboration with Rijkswaterstaat.

Firstly, the five general principles of SE, which were found in the literature study, were compared with the five general principles of SE that are applied within Rijkswaterstaat. These principles were analyzed one by one, not just the interpretation behind the principles but also similarities and relationships became visible. What turned out was that the general principles of SE as a result of the literature study fit in seamlessly with the five **general principles of SE** that are applied in practice within Rijkswaterstaat. Table 3.1 below shows the various general principles of SE and also the link that has been made between theory (literature study) and practice (Rijkswaterstaat).

Table 3.1: Link of general principles of SE between theory and practice

General principles of SE		
Theory: Literature study		**Practice: Rijkswaterstaat**
Systems thinking	=	Systems thinking
Customer management	=	Customer needs
Integral approach	=	Optimization life cycle
Design flexibility	=	From abstract to specific
Requirements management	=	Explicit working

Subsequently, Rijkswaterstaat has translated these five general principles of SE into a process description. This process description describes the application of SE for projects within Rijkswaterstaat. When the process description is analyzed, can be seen that it consists of four main processes: structuring the project, analyzing and determining the customer requirements, designing and specifying the system specification and finally the elaboration of the contract specification. Each of these main processes consists of its turn of several process steps. The relationship between these process steps and main processes is important and becomes visible through three important specifications: customer requirements specification, system specification and contract specification.

Finally, **bottlenecks** within the process description have been identified and analyzed with the aid of the conducted case study and interviews. The bottlenecks are divided into two categories;

The bottlenecks in construction and maintenance projects, in general, relate to:

- Bureaucracy; *with regard to the activities per process step*
- Verification & Validation; *ambiguity and unclear*
- Three specifications; *uncertainty and unknown*
- 'Checking' process steps; *redundant*
- General design of the process description; *disagree with design*

The bottlenecks in maintenance projects, in particular, are as follows:

- Bureaucracy; *with regard to maintenance products/processes*
- Terminology; *confusion and difficulty*
- Role division of the IPM-team; *designated roles*
- Internal and external stakeholders; *do not fit due to differences*
- V&V paragraph; *unknown and unclear*
- V&V concerning the customer; *poor execution and knowledge*
- V&V concerning the system; *caused by other related bottlenecks*
- Design process step; *wrong illusion, lower abstraction level*
- Analyze and manage project assignment; *major influence on design*

4. Methodology

In the previous chapters the problem of this research has already been clearly described and examined. With the aid of this chapter, methodology, the identified problems must be solved systematically with the help of the right methods, in order to ultimately achieve the aim of this research. This chapter describes why, which and how the methods have been applied and the way in which data have been collected and analyzed.

4.1 Methods

Various methods will be applied within this research, this is necessary because this research will ultimately consist of two different end products (models). In order to be able to substantiate the choice of methods, it is therefore necessary to gain some insight into the two final models. The first model, a **process model**, forms an addition to the already existing process description SE (for construction projects) and will be applicable for major maintenance projects (in particular: the production line B within Rijkswaterstaat). The second model is a derivative of the first product, namely an **information model** for the element 'measure'. Further, more in-depth, information about these two final models can be found in the following chapters (chapter 5: process model and chapter 6: information model). All in all, various and specific methods are needed for these two models.

The first, more general, method that was applied is the case study method, this method was used to design, implement and validate the process model of the process description SE for major maintenance projects. The second, more specific, method that was applied is the Model-Based Systems Engineering (MBSE) method, in order to create the 'measure' information model. Both methods will be described below: the theory, advantages and disadvantages, appropriateness and the application thereof will be explained.

Case study method

The case study method is a form of qualitative research, with the aid of this method the problem is addressed in depth and all underlying reasons and motivations become obsolete (Yin, 1994). Typical characteristics of this method are therefore the qualitative, intensive and selective data generation, the in depth and the small number of cases (Verschuren, 2010). According to Yin (1994), the case study method is advisable if the research question has a 'how' or 'why' form, if the researcher has little or no influence to control the behavioral events and if the research relates on phenomenon in a real-life environment, which all three apply to in this research. Within this method there is still freedom to make a choice about the design and type of the case study and the way in which data is going to be collected (Yin, 1994).

Within the case study design, there is a choice between a single and multiple case study. Within this research a single case study was chosen because when an individual case is examined, the research is carried out more in depth and more insight is gained into the problem and the case itself (Verschuren, 2010). The **single case study** was also chosen because this research concerns major maintenance projects within the production line B of Rijkswaterstaat, all the projects within this production line are of the same nature and seem very similar, which makes it unnecessary to examine multiple cases within this same production line because probably the same findings will be obtained (more information about the production line B can be found in section 4.2.1).

The type of case study can differ between explanatory, exploratory and descriptive (Yin, 1994). The choice was made for an exploratory, orientating, type of case study because knowledge must be gained from the working method of a specific team, project and organization.

Data can be collected and obtained in various ways. Important when collecting data is to consult different and multiple sources of evidence, this is also called **triangulation**. Triangulation ensures that the collected data is more reliable and due to the repeatability of the data collection, the validity of the results and therefore also the research increases (Verschuren, 2010). From the point of view of data triangulation, has been chosen for multiple qualitative data collection methods, namely document analysis and interviews (Yin, 1994). These data collection methods are described in more detail in paragraph 4.2.

It is important to consider the advantages and disadvantages of the different methods and also to consider whether the benefits really add value and the downsides can be reduced or even eliminated. One of the main advantages of the case study method is that it is a relatively simple and flexible method, therefore not much work is required in advance and an overall clear image of the results can be formed quickly (Verschuren, 2010). Another advantage is that the final results have a lot of depth and that these results are also often immediately and easily accepted by the people within the relevant field, because they often identify the results easily (Verschuren, 2010).

However, because the results of a case study method are so specific and recognizable for certain people and projects within the relevant field, this also entails a disadvantage of this method. A disadvantage of this method is that the results are often difficult to apply to a broader audience or other cases, in other words; the external validity of the results is low. Though, this is less important for studies that are practice-oriented because these studies and results do not necessarily have to apply to other external cases (Verschuren, 2010). This research is being carried out for and in collaboration with Rijkswaterstaat, which therefore makes the research practice-oriented for major infrastructure maintenance projects within the production line B of Rijkswaterstaat. Thus, therefore this disadvantage is negated for this research.

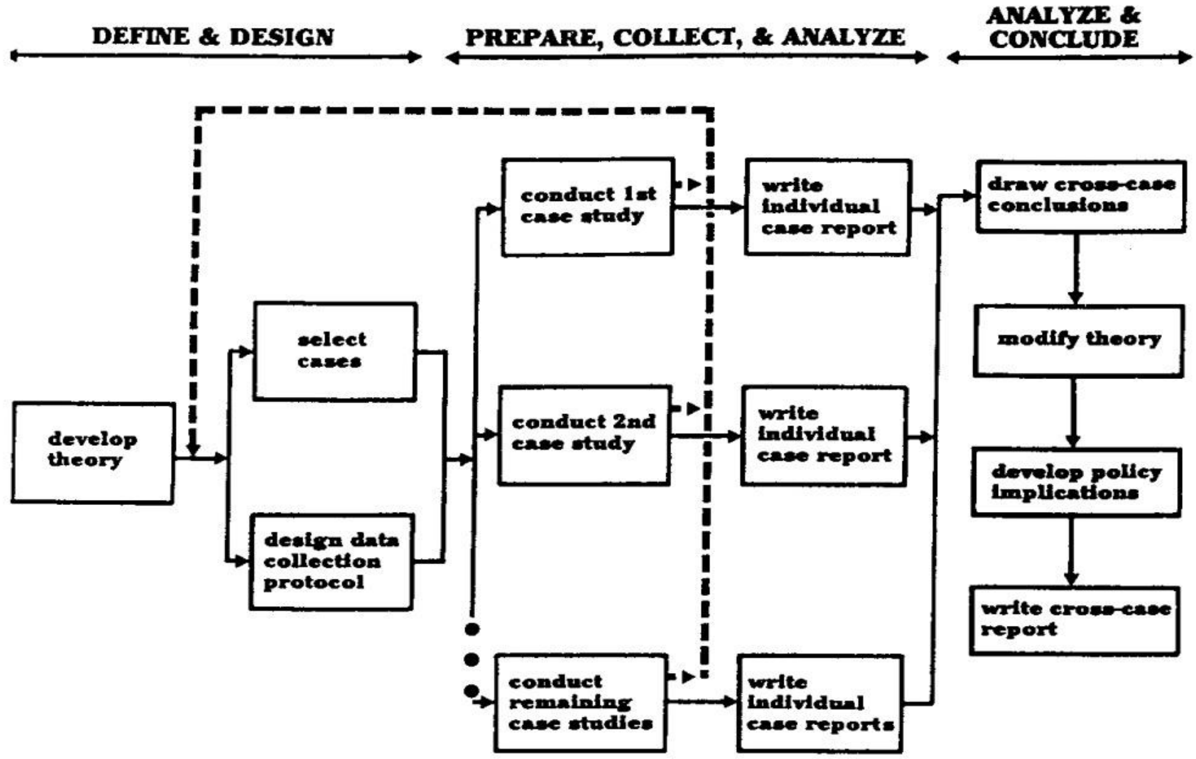


Figure 4.1: Case study method (Yin, 1994)

The process, to go through all the aforementioned aspects of the case study method and carry it out properly, is shown in figure 4.1 (Yin, 1994). Although this figure represents a multiple case study method, it can also be applied for a single case study. At the start of the process it is important to select the right case, then the case study can be conducted and the data collected, after analyzing this data the results can be worked and written out (Eisenhardt, 1989).

Model-Based Systems Engineering method

The Model-Based Systems Engineering (MBSE) method is a method that connects to the SE process and produces a model as the primary end product (Steiner, 2015). According to INCOSE (2016), MBSE is “the formalized application of modeling to support system requirements, design, analysis and verification and validation activities, beginning in the conceptual design phase and continuing throughout development and later lifecycle phases”. The MBSE method creates a **model-based** approach by creating a model, instead of an original document-based approach (Lockheed Martin, 2015). Therefore, this method takes away the disadvantages of a document-based approach by providing a model in which system requirements, design, analysis and V&V information are integrated (Steiner, 2015). In order to be able to specify and design such a model, the process of the MBSE method must be followed and the associated activities must be carried out (figure 4.2).

It is important that these activities are carried out iteratively (Steiner, 2015). The first activity ‘organize the model’ consist of, as the name itself already suggests, organizing the model.

Subsequently, the stakeholders needs need to be analyzed, insight must be gained into the problem of the customer, the question behind the question, which stakeholders are involved and what their requirements and wishes are and how these can be measured and delivered in the end. The third activity is to specify the system requirements, it is important that the customer requirements are solution-free specified and are applicable to the final system. During the 'synthesize alternative system solutions' activity the possible alternative solutions and designs, that meet the previously established system requirements, are analyzed.

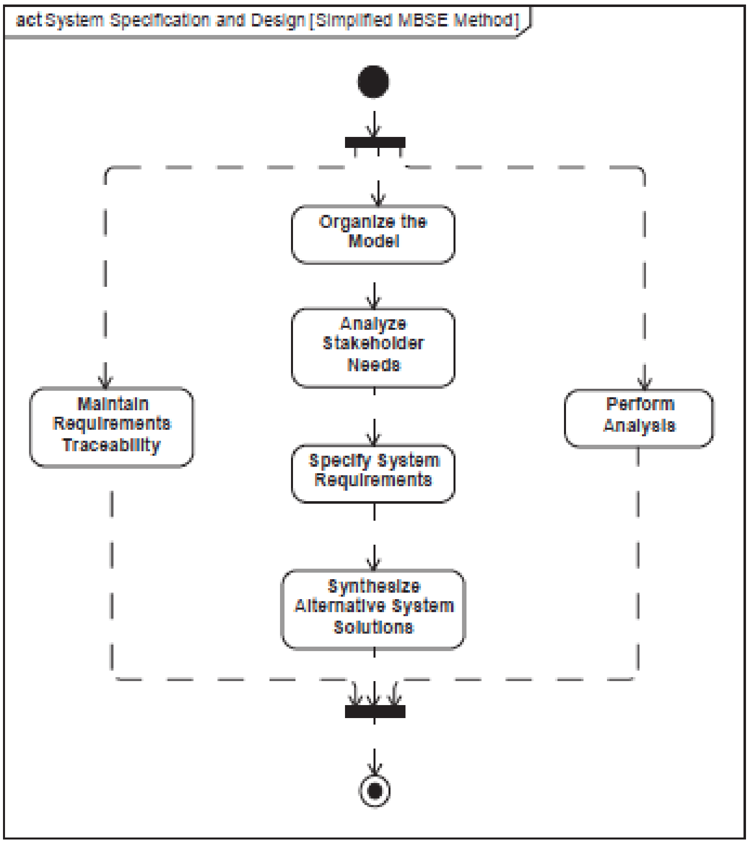


Figure 4.2: Model-Based Systems Engineering method (Steiner, 2015)

Thereafter, during the activity, perform analysis, the alternatives are analyzed again and eventually one system solution is chosen that meets all the requirements. In the last activity it is not only important that the chosen system meets all the requirements, but mainly that this can also be demonstrated. It is important that the requirements for traceability are maintained in a way that links are visible between the customer requirements, functions and solutions and that therefore the system can continuously be verified and validated (Steiner, 2015). The result of all these activities together is therefore a model that meets the stakeholder's needs.

Advantages of a model include that a model, instead of a document, provides a clear, complete, consistent and traceable overview (Wolfrom, 2011). Other important benefits are the increasing ability to manage complex systems, the connection to and application of SE principles and information management by capturing and tracing all knowledge and information.

However, a disadvantage is that the software tools for applying this method and creating the final model in an ICT environment, generally requires a lot of money, effort, discipline and knowledge (INCOSE, 2016). Nevertheless, this disadvantage is not entirely applicable to this research because the model is created in the form of an **information model**. A MBSE information model can be defined using a modeling language (Steiner, 2015). A familiar and unified modeling language for systems modeling is Unified Modeling Language (INCOSE, 2016). The final UML information model is very important input for the further translation of this system model into a digital information management system. Because this research is carried out for and in collaboration with Rijkswaterstaat, the information model need to be translated into the digital information management system of Rijkswaterstaat, namely GRIP in Relatics. This further translation can and should only be carried out by a team of specialists within Rijkswaterstaat. This eliminates the disadvantage of this method and a model is still created, but in the form of an information model instead of a further translated digital model in a software tool.

4.2 Data collection

In order to collect data for this research, it was chosen to combine and apply multiple qualitative data collection methods, namely document analysis and interviews based on case studies of projects of Rijkswaterstaat (because this research is conducted for and in collaboration with Rijkswaterstaat). This has been chosen because, as previously mentioned, it is important that data is collected on the basis of different and multiple sources of evidence, this is also called triangulation. Triangulation therefore ensures that the collected data is more reliable and due to the repeatability of the data collection, the validity of the results and therefore also the research increases. Altogether, in this section, the two qualitative data collection methods are explained and discusses in more detail.

4.2.1 Case studies

The document analysis is carried out on the basis of specifically selected case studies. As a result the collected data is not based on documents from the literature, but in contrary the data is actually obtained by analyzing existing documents from already existing projects, namely the selected case studies.

Important to know is that two case studies are selected and used for this research, therefore the data collection is performed twice. The case studies are two major variable maintenance projects (in Dutch better known as GVO) from the B-roads production line from the region Western-Netherlands-South; the project assignment of 2018 and 2019 (in Dutch better known as POF 2018 and 2019). The first consulted case study is the **project assignment of 2018** and is used to design and implement the models (chapter 5 and 6), the second case study is consulted to validate the concerned models (chapter 7) and is the **project assignment of 2019**. In order to be able to explain and substantiate the choice for these selected case study projects, it is important that more background information is given about these projects of Rijkswaterstaat.

The aim of this research is that the already existing process description SE, which is currently only applicable for construction projects, becomes also applicable for maintenance projects, which ensures that the maintenance projects can be completed in a more effective and efficient way through the application of SE. Therefore, the focus in this research is on maintenance projects.

Within Rijkswaterstaat, the maintenance projects are, together with the construction projects, part of the construction and maintenance process (in Dutch better known as ‘Aanleg & Onderhoud’ process). Within this process, interventions in the physical infrastructure networks are prepared and executed which are necessary to maintain, renew or extend the functionalities and performance of these networks (Rijkswaterstaat, 2016). In order to organize and execute these maintenance projects as optimal as possible, the risks of these projects are controlled by risk-based portfolio management. That is why Rijkswaterstaat has subdivided the maintenance project into four production lines. These four production lines, A to D, each consists of maintenance projects with similar characteristics and risk profiles (Rijkswaterstaat, 2016). As a result that the projects within a production line are largely comparable and identical which means that risks can be better managed. Production line A consists of fixed maintenance projects; to maintain the network. Variable maintenance, in contrast to fixed maintenance, belongs to production line B; these projects improve and renovate the network. The projects in production line C ensure the expansion of the network. The last production line, D, consists of the control of programs. The selected case studies for this research are, as mentioned before, two major variable maintenance projects, so projects from the production line B.

The choice for these case study projects within this production line is based on several aspects. First of all, it is important that the case study projects contain enough, useful and traceable information and documents and also make them available for research. Also important is that the various parties involved in the projects are willing to conduct interviews, the **IPM-team** (integral project management team) of these projects is a very cooperative and well-willing team. The choice of only these two case studies is also based on the high percentage of the so called 'green flow', namely 90% of the projects within the production line B are standard and are executed exactly according to the process. Only 10% of the projects are in the 'red flow', these projects are not standard but are a matter of customization. So, it can be assumed that the most projects within this production line are identical, whereby the importance of a multiple case study is invalidated and therefore a single case study can be carried out for this research. Finally, it is important that the project has some affection with the main subject of this research, namely SE. The IPM-team of the case study projects has already made a start with the application of SE within their projects and has indicated that they are prepared to further implement SE and are open to feedback, support and management.

The case study projects thus belong to **production line B**, therefore more information about this production line is necessary to gain insight into the case studies itself and the further research. The production line B is also subdivided in its turn, namely in B-roads, B-bridges and B-waterways. The selected case studies in this research belong to the B-roads line, these are also the most common projects within this production line. Despite the fact that these two case studies are being consulted, it is important that the final advice and product not only fit in and apply to only these two projects, but to all the B-roads projects. As mentioned earlier, the B-roads projects aim to improve and renovate the network, this variable maintenance can be divided into small fixed variable maintenance and major variable maintenance, the ratio between these two is shown in figure 4.3 below (Rijkswaterstaat, 2016).

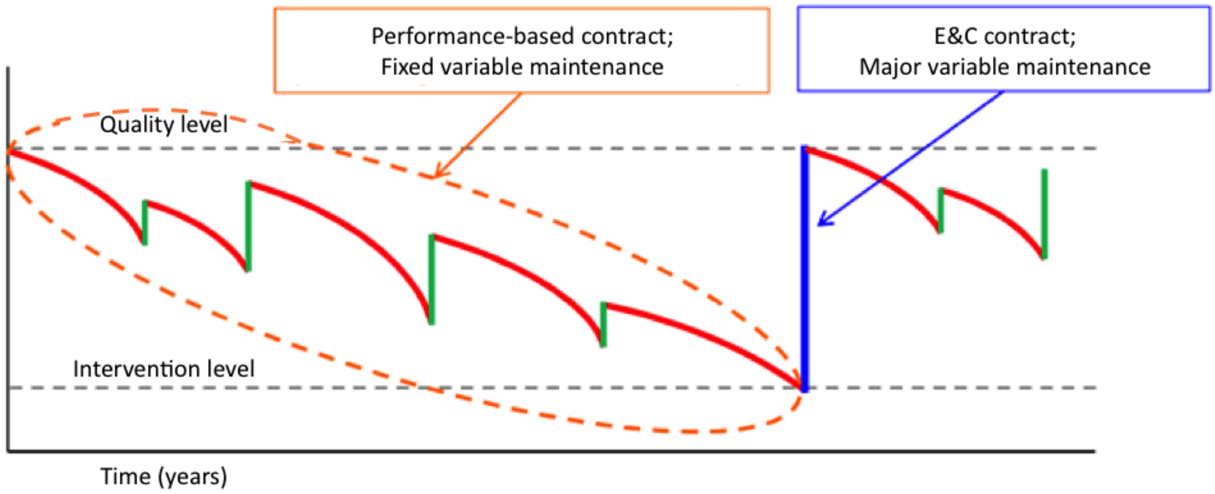


Figure 4.3: Variable maintenance (Rijkswaterstaat, 2016)

The existing networks of Rijkswaterstaat are often inspected, fixed variable maintenance prevents that the quality of these networks decreases below the intervention level and ensures that the quality level of the networks increases (Xiang, 2017). Large variable maintenance will only be carried out if the network no longer meet the minimum quality level and thus if the intervention level is reached. E&C contracts are used for large variable maintenance projects, within this contract type the contractor is responsible for bringing order and the proper functioning of existing objects and systems (Rijkswaterstaat, 2016). E&C is mainly focused on major variable maintenance on asphalt and concrete hardenings and 'simple' civil structures on state roads (mainly highways), including additional work (Rijkswaterstaat, 2016). The regions of Rijkswaterstaat determine, on the basis of further and more detailed research, the exact maintenance measures. These maintenance measures form the technical basis for the projects assignment for the IPM-team. Each IPM-team consists of five team members, namely a project manager, technical manager, environmental manager, contract manager and manager project management. Together they are responsible for translating the project assignment, from the region into a contract specification which serves as a demand for the market, of major variable maintenance B-roads projects.

4.2.2 Interviews

The qualitative research is carried out by, among other things, extracting and collecting detailed information by conducting in-depth interviews, this is also one of the most widely used and most flexible methods for gaining qualitative information. It has the advantage that it is an interactive way of collecting data, therefore it is possible to for example ask for clarification or give another or more in-depth direction to the conversation (Muller, 2013). Different formats for interviews are possible, a semi-structured design has been chosen. **Semi-structured interviews** are a compromise between a highly structured and an unstructured interview, this creates a reasonably structured interview but with space for any new ideas, opinions, experiences or discussions about other related topics (Lenferink, 2013). The structure of a semi-structured interview usually consists of several topics and various open questions, this creates freedom and flexibility but also some control and more in-depth information on interesting problems (Lenferink, 2013).

The interviews will be conducted with all five team members of the **IPM-team** of the relevant case study projects. The entire IPM-team will be interviewed twice, first to gain insight into the current situation of the application of the process description SE (identifying some bottlenecks of its application in maintenance projects, see appendix I till V) and ultimately a second time to validate the end product; a lay-on note of the process description SE for maintenance projects, the process model (check if the bottlenecks are actually have been taken away).

Each interview will consist of the same structure, namely a welcome word, a brief introduction, the open-ended questions themselves and finally a wrap up and acknowledgments.
The questions for the interviews that are conducted first, with regard to identifying the bottlenecks of the application of the process description SE in maintenance projects, have already been prepared. These five questions are asked at each process step to the responsible team member of the IPM-team. The questions are as follows:

1. *The process description SE prescribes that the IPM team member as '… manager' is responsible for this process step. Is this also the case in real practice of this project? If not: which IPM team member is responsible?*
2. *Does the aim of this process step (of the process description SE) correspond to the aim of this process step in this project? If not: what should be an appropriate aim for this process step?*
3. *What input is needed to complete this process step? (If this does not corresponds with the input of the process description SE, then ask why was chosen to deviate from this)*
4. *What is the desired output to complete this process step? (If this does not corresponds with the output of the process description SE, then ask why was chosen to deviate from this)*
5. *What specific activities should be carried out during this process step? (If this does not corresponds with the activities of the process description SE, then ask why was chosen to deviate from this)*

After each question there is space for additional comments or questions, not only about a specific process step but also about the coherence between the process steps or the process description SE as a whole.
The questions for the second interview for validation have not yet been drawn up, this depends on the end product, but probably the questions will also be drafted and dealt with per process step as shown above, but then it will be about whether or not and to what extent the bottlenecks have been taken away by the use of the end product.

5. Process model

This chapter focuses on the first and main model of this research, namely the process model. The process model is designed in the form of a lay-on note, for the already existing process description SE, which applies to major infrastructure maintenance projects. Firstly, the design of the process model is described, then the model is actually implemented and finally validated.

5.1 Model design

According to Steinmüller (1993), a model is information on something, created by someone, for somebody for some purpose. A model therefore has an origin and is based on this, also a model only applies to a specific situation (Stachowiak, 1973). In this chapter, a model in the form of a process model is designed, implemented and validated. A **process model** is a model in which similar processes can be combined with the aim of describing how processes should actually be carried out, in contrast to how the process actually takes place (Rolland, 1998).

The process model is based on the already existing process description SE of Rijkswaterstaat. In the previous chapters it has already been described that this process description was originally made for and applies to construction projects and therefore does not always connect or apply to maintenance projects. The bottlenecks that cause this have been investigated and identified, by using the case study method. Therefore, the aim of this model is to **eliminate** the **existing bottlenecks** and to ensure that with the aid of a lay-on note, the process description also becomes applicable to maintenance projects (from the production line B of Rijkswaterstaat).

The design of this process model is therefore in the same form as the already existing process description, namely consisting of all the process steps (P1-P6, K1-K7, S1-S9 and C1-C4) and the interpretation and deepening of each process step consisting of the purpose, input, activities and output. This has been deliberately chosen, so that it is recognizable and unambiguous for the IPM-teams and other users within Rijkswaterstaat, regardless of whether they are working on a construction or maintenance project.

5.2 Model implementation

The substance of the design of the process model is given on the basis of the collected data after applying the case study method. The relevant major infrastructure maintenance project, the project assignment of 2018, was used as a case study. Documents have been analyzed and interviews have been conducted with the entire IPM-team of this project. By comparing these collected data with the already existing data (the data from the already existing process description SE), differences and bottlenecks, as well as similarities, emerged clearly per process step.

Based on this, the lay-on note for the process description for maintenance projects has been filled in, by checking per process step whether the existing data corresponds or differs from the data obtained. In case of similarities between the already existing data and obtained data, this was confirmed in the process model and simply shown by using a ✓, this symbol shows that there are no clarifications or additions on the current process description. If, on the other hand, the existing data did not match with the data obtained, this difference (in the form of **clarifications**, **additions** or **not applicable**) was examined and explained in detail in the relevant process step. The explanations of these changes, additions or exceptions to the existing process description are based and derived from the literature in the field of SE and infrastructure maintenance projects. In this way all process steps have been completed. All these process steps together form the process model; the lay-on note for the process description that ensures that it is also applicable for maintenance projects from now on. The process model can be found in appendix VI, but some process steps will be explicitly explained below.

The choice was made to describe four process steps in more detail, each process step from one of the four main processes. This was deliberately chosen, so that all main processes are included and explained. These four process steps are selected because the bottlenecks that were found to be important can be specifically assigned to these process steps, but also because all previous identified bottlenecks are addressed and eliminated in at least these four process steps. The process steps that are explained in more detail below are P1 ‘analyze project assignment’, K3 ‘identify customer requirements’, S5 ‘design’ and C3 ‘compile contract specification’. The previously identified bottlenecks are therefore treated and eliminated in at least all four process steps, namely the bottlenecks related to bureaucracy (P1, K3, S5), terminology (P1, K3, S5), role division (C3), stakeholders (K3), V&V (K3), design process (P1, S5) and project assignment (P1, S5).

5.2.1 Project assignment

The results of the case study method showed that in the first process step (P1 analyze project assignment) of the process description, many bottlenecks are experiences by the project manager, which is the responsible IPM role holder for this process step. These identified bottlenecks are related to bureaucracy, terminology, the design process and the project assignment. By adding two additions and three clarifications, the identified bottlenecks experienced in this process step have been eliminated (table 5.1).

The first addition related to the aim of this relevant process step. The objective, as formulated in the current process description, was specifically focused on construction projects, in both the area of terminology and in relation to the activities that need to be carried out. The terminology used and the associated activities of this process step are not applicable to maintenance projects. With this first addition in table 5.1, the aim of this process step for maintenance projects has become applicable and therefore also more understandable.

The second addition in this process step applies to the activities that need to be carried out. The activities, as described in the current process description, were in line with the aim of this process step and therefore formulated very specifically from the point of view of construction projects and the associated products and terms used in these projects. Many activities that have been described, cannot or do not need to be performed in maintenance projects. With this addition, the activities of this process step match with the aims, products and terms used in maintenance projects from now on.

The input, as described in the current process description, is applicable for construction projects as well as maintenance projects. However, bottlenecks are still experienced due to the construction projects related terminology used. The clarification in this process step consists of an explanation of the terms, in order to make clear that the input is the same despite the use of other terminology.

Table 5.1: Process step P1: analyze project assignment

Structuring the project **P1 Analyze project assignment**	
IPM-role	Project manager
Aim	*Addition:* It is important to gain insight into the feasibility and achievability of the project assignment, as defined in the project assignment form.
Input	*Clarification:* - Project assignment = in construction projects the project assignment is processed in the scope form of the assignment letter, while in maintenance projects the project assignment is processed in the project assignment form. - (Source)documentation of the project = for maintenance projects think about, for example, the measure list (better known as RUPS)
Activities	*Addition*: The activities in the current process description, that need to be carried out, are based on the structure and content of the scope form, but the activities for maintenance projects must be based on the structure and form of the project assignment form. Thus, the following activities, based on the project assignment form, must be carried out: - Analyzing the project assignment form (current situation, objective, demarcation etc.) and the source documentation of the project (think of, for example, the RUPS measure list). - Analyzing the budget, planning, environmental management, public-oriented network management, risks, information transfer, process appointments and other data for the execution of the assignment.

Structuring the project P1 Analyze project assignment	
	Clarification: This process step, together with process step P6 (manage scope and project plan), has a major influence on process step S5 (design). Therefore, an important aspect of this process step is to use the project assignment form (including RUPS measure list) to examine, elaborate and define the scope as good and detailed as possible. For example, often it is not yet known to what extent a damage is only visual (low abstraction level) or even also constructive (high abstraction level). Therefore, it is important that the IPM-team is aware of this and conduct further research, to find out as early as possible what the actual damage is, because this can have a major influence on the design process (S5) and associated the abstraction level of specifying.
Output	*Clarification:* - Scope form = (signed) project assignment form

The bottleneck that is experienced with regard to the used terminology for the input of this process step, is also experienced for the desired output. This bottleneck has also been eliminated with the aid of a clarification that relates to the terminology used. This clarification makes clear that the same output is desirable in both construction as maintenance projects, but the difference herein is only in the terminology.

The last clarification relates to the activities of this process step, but also has a major influence on important process steps that will follow. This clarification is mainly added in order to create awareness for the importance of the activities that need to be carried out already in this process step. So that the identified bottlenecks in other process steps that will follow and are related to this process step, already can be partly eliminated.

5.2.2 Customer requirements specification

In the main process of ‘analyzing and determining customer requirements’, various bottlenecks have also been identified, which mainly relate to bureaucracy, terminology, stakeholders and verification and validation. By adding two clarifications and one exception, the bottlenecks in this process step are eliminated and therefore this process step is also applicable for maintenance projects (table 5.2).

The input needed for the environmental manager to perform this process step properly has been clarified, this was necessary because the terminology used in the current process description it not fully applicable and recognizable for maintenance projects. Therefore, the input is clarified with the help of maintenance specific terms and a more detailed explanation of the products.

Table 5.2: Process step K3: identify customer requirements

Analyzing and determining customer requirements K3 Identify customer requirements	
IPM-role	Environmental manager
Aim	✓
Input	*Clarification:* - Stakeholder overview = stakeholder overview of, mostly, only internal stakeholders - Discussion notes and reports from consultations with stakeholders = think for example of the document ‘traffic management’ of the ‘Less Nuisance’ team and an overview of the requirements of the district
Activities	*Not applicable*: During the execution of the activities, as described in the current process description SE, it should be kept in mind that the nature, quantity and complexity of the stakeholder requirements is very different between construction and maintenance

Analyzing and determining customer requirements **K3 Identify customer requirements**	
	projects (in maintenance projects these activities are applicable to a lesser extent, mainly two important internal stakeholders are involved, namely the district (requirements in project assignment form) and the 'Less Nuisance' team (requirements in the 'traffic management' document). Therefore, the activities often only apply to internal stakeholders in maintenance projects (and rarely apply to external stakeholders, these are often secured and represented by internal stakeholders). *Clarification*: From the point of view of process steps P5 (V&V paragraph project plan) and S8 (verify and validate the system), it is important that the activities with regard to making agreements about V&V activities with stakeholders must certainly be carried out (think for example of making agreements about when the customer is satisfied, method of proof, criteria, evaluators, V&V phase etc.). These activities are important, especially with the two most important internal stakeholders of maintenance projects, namely the district and the 'Less Nuisance' team.
Output	✓

The activities that need to be carried out in this process step are partly not applicable and partly clarified. The previous chapters have already shown several times that the stakeholders involved in construction and maintenance projects differ greatly. As a result, bottlenecks are experienced in, among others, this process step with the activities that relate to the stakeholders of a project. For example, the activities that are related to external stakeholders are often not applicable in maintenance projects and therefore cannot be carried out. Described in this process step is why these activities cannot always be and need to be carried out in maintenance projects, as a result of which the bottlenecks related to bureaucracy and stakeholders are eliminated.

In the application of the process description in maintenance projects, also bottlenecks have been identified that relate to verification and validation. By clarifying the activities related to V&V in this process step, the bottlenecks concerning V&V can be eliminated in this process step, but also in the subsequent process steps. This clarification mainly creates awareness of the influence of these activities on further activities and process steps related to V&V, in order to be able to properly perform the V&V.

5.2.3 System specification

The technical manager, the responsible IPM role holder of this process step (S5 design), has experienced many bottlenecks in this process step. These bottlenecks mainly related to bureaucracy, terminology, designing and the project assignment. These bottlenecks have been eliminated by adding a detailed clarification and an exception (table 5.3).

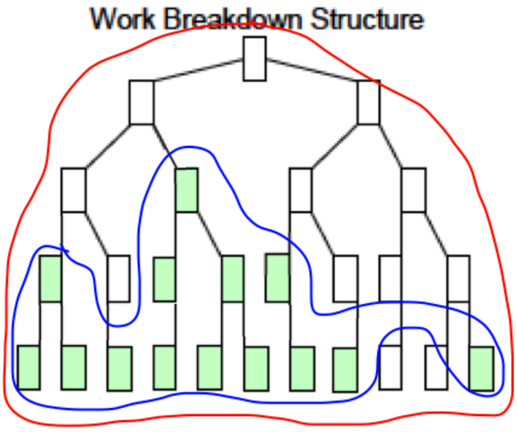
The bottlenecks that were experienced in this process step were that major that this entire process step was not carried out in maintenance projects. The illusion existed that this process step only applies to construction projects, this was caused by the current process description because it describes many specific examples, terms and products that are related and apply to construction projects. As a result, the content of the process description cannot be translated and applied in maintenance projects.

Many of the products that were found necessary as input of this process step are not applicable in maintenance projects, because these products and associated activities simply do not and cannot be carried out in maintenance projects. This is because maintenance projects are rarely complex and almost never have to deal with interfaces, in contrast to construction projects that are often very complex and have to deal many interfaces. With the aid of this exception is made clear which input is not always applicable for maintenance projects.

The activities in this process step have been clarified in a very detailed way, this was deemed necessary in order to take away the illusion that this process step, thus designing, cannot and does not have to be carried out in maintenance projects. The clarification consists mainly of examples of making design choices in maintenance projects, with the help of these maintenance- and practice-oriented examples, the SE theory with regard to designing can be translated and applied much more easily. These clarifications created the awareness that designing and making design choices also occurs in and applies to maintenance projects, despite the different level of abstraction in construction and maintenance projects.

Table 5.3: Process step S5: design

Designing and specifying the system specification **S5 Design**	
IPM-role	Technical manager
Aim	✓
Input	*Not applicable*: Applicable, if present from previous process steps: - Function analysis report - Interface analysis and context diagram (possibly including interface management document) - Aspects analysis (possibly including the RAMS analysis)
Activities	*Clarification*: The assumption exists that no designs are made in maintenance projects, because the work already exists and only needs to be brought back to the desired conditions. In maintenance projects, many aspects and data are already fixed (think for example of the measures and SLOT's), but the assumption that no designs are made in maintenance projects is incorrect, design choices are certainly made. The examples of designing from the current process description and the well-known design examples in general (think of the familiar example: 'create a shore connection from A to B', this can be fulfilled by making a design choice for a bridge or a tunnel), are specifically focuses on construction projects and designing at a high level of abstraction. The examples of designing and making design choices are also certainly applicable in maintenance projects, but often at a lower level of abstraction, as a result of which design choices are often not recognized while they are actually present and, consciously or not, are made. Some examples of design choices in maintenance projects: - A damage has been detected, namely the pain of a fence is peeling off. A measure has been proposed for this damage, namely 'the paint needs to be replaced', a design choice is already being made here and also further design choices can be made, think for example of design choices concerning the type of preservation system or material characteristics such as chemical composition or color etc. - Another damage has been found, namely the road surface is damaged. A measure has been proposed for this damage, namely 'the road surface needs to be replaced'. In this example, a design choice has to be made for a new type of road surface, for example the choice between applying porous or soundless asphalt as road surface. - In case of the previous example, a design choice was made at a low abstraction level, but this can always be brought to a higher level of abstraction. If, for example, the damage of the road surface is not only visual, but proves to also be constructive. In this case, design choices need to be made concerning the foundation, which is at a higher abstraction level (which already seems more like design choices made in construction projects).

Designing and specifying the system specification S5 Design	
	The abstraction level of specification and designing is roughly shown in the figure below. In construction projects (red frame), the level of abstraction starts at the highest level of abstraction and then more and more on a lower abstraction level. In maintenance projects (blue frame), the abstraction level of specification and design is determined and influenced by the abstraction level of the system elements within the project scope, which often is at a lower level of abstraction in comparison with construction projects. 
Output	✓

5.2.3 Contract specification

The interpretation of the process step (C3 compile contract specification) is very focused on construction projects, which is why various bottlenecks were also experienced in this process step. These bottlenecks have been eliminated by adding one clarification and two additions (table 5.4).

The clarification in this process step related to the role division per process step, in the current process description the technical manager is the responsible IPM role holder of this process step. Confusion arose because the contract manager is not mentioned in this process step, while in maintenance projects the cooperation between the technical manager and the contract manager is very important due to the application of specific maintenance contract types (a different division of roles per contract type). The clarification explains that despite the fact that the technical manager is the responsible IPM role holder of this process step, the cooperation with and support of the contract manager is very important in maintenance projects.

The two additions in this process step, eliminate the identified bottlenecks caused by the different types of contract types that are applicable in maintenance projects in comparison with construction projects. In the current process description, the input and output of this process step are specifically focuses on contract types that only apply to construction projects, these bottlenecks have been eliminated by the describing the input and output that doe apply to contract types that are used in maintenance projects.

Table 5.4: Process step C3: compile contract specification

Elaboration of the contract specification C3 Compile contract specification	
IPM-role	*Clarification*: The responsible IPM role holder for this process step, as described in the current process description, is the technical manager. The technical manager provides the performed work (the demand specification requirements) to the contract manager. After that, the contract manager is responsible for the coherence of all the contract documents. Therefore, the cooperation between the technical manager and contract manager is of great importance in this process step.
Aim	✓

<table>
<tr><th colspan="2">Elaboration of the contract specification
C3 Compile contract specification</th></tr>
<tr><td>Input</td><td>Addition:
- Models for the tender dossier (think for example of annexes and enrollment- and assessment documents etc.)</td></tr>
<tr><td>Activities</td><td>✓</td></tr>
<tr><td>Output</td><td>Addition:
Due to the different contract types in construction projects (D&C and DBFM contracts) and maintenance projects (E&C and performance-based contracts), the output of this process step differs per contract form. The output for maintenance projects is as follows:
- E&C contract: Demand Specification Requirements and Demand Specification Process
- Performance-based contract: general demand specification</td></tr>
</table>

5.2.4 Verification

It is important and necessary that the process will be verified. The **SE-team** of the Technical Management Advisory department of Rijkswaterstaat conducts the first **verification** moment of the process model. These specialists provided feedback on different aspects, mainly on the SE aspect but also on the infrastructure and maintenance aspects of this process model. The feedback was mostly related to the even stricter formulation of the explanations in relation to SE, so that these can always only be interpreted in the same and correct manner and also corresponds to the specific jargon used in infrastructure maintenance projects. This verification moment with the SE work field led to useful feedback and is processed in the process model.

After this first verification moment, the process model has been also verified for a second time. This time by the IPM-team of the relevant case study, they have checked the process model, in contrast to the SE team, mainly on the part concerning the technical and substantive part of infrastructure maintenance projects and checked to a smaller extent on the SE aspect of the process model. Because of the different expertises of the IPM-team and SE-team, they complement each other well, this is the reason why there is chosen to carry out two verifications.

Thus, the **IPM-team** has also verified the process model after the **verification** moment of the SE work field. All five IPM-team members have verified the process steps for which they have the main responsibility, so all process steps have gone through. As mentioned before, the IPM-team has mainly checked the technical aspect, concerning major maintenance infrastructure projects, of the process model. This resulted in a few small proposals to describe the content, where necessary, in a clearer or more detailed manner. The main proposal concerned the clarification of indicating the responsible IPM-team member per process step. In the first instance, only exceptions to the existing process description where mentioned, but it was found desirable by the IPM-team if the responsible IPM-team member was appointed at each process step instead of just mentioning the exceptions. All this has been included and adjusted and forms the latest version of the process model. The final process model, which will be used from now on by the IPM-teams for major infrastructure maintenance projects of the production line B, can be found in appendix VI.

5.3 Model validation

In the previous section, the process model was verified, which guarantees the substantive quality of the process model and is, where necessary, improved. The verification was the **check if it is done right**, but the validation still has to **check if the right thing is done**, this difference is important and essential. Validation should be conducted into whether the process model is actually what the IPM-team wanted and deemed necessary and whether it can actually solve the previously identified bottlenecks which were encountered during the application of the already existing process description in maintenance projects.

The validation of a model is the process of determining the extent to which the model meets the intended use of the model (Steiner, 2015). This validation can be carried out in different ways and depends on the type of model, in this case the model is in the form of a process model. In this research, a qualitative research, the validation by **review of experts** is one of the most used and most capable of ensuring the validation of a model (Sandelowski, 1998). Important for the validation is that the right domain experts are selected, a distinction can be made between internal or external experts and also in the field of type of expertise, think for example of specific product experts (for example experts with experience with the process description SE) or domain experts (for example experts in the field of SE or in the area of infrastructure maintenance projects) (Wilson, 2013).

In this research was decided to have the reviews carried out by internal experts only, namely by all the team members of the **IPM-team** of the relevant case study, who also will actually use the process model in the near future. Because of their experience in both maintenance projects and their experience with the application of the already existing process description SE, these IPM-team members are both specific product- and domain-experts and therefore can give a review that not only relates to the product but also to the overarching and associated processes. In addition to this added value, another benefit is that it has also been proven that reviews by internal experts are more valuable than reviews by external experts. This is because external experts often cannot provide enough information and have less insight into the product and associated processes because these are often very project specific (Morse, 1994).

It is important to consider the advantages and disadvantages of this validation method and also to consider whether the benefits really add value and the downsides can be reduced or even eliminated. Review by experts has the advantage that it is freely accessible to every researcher because no extra costs, products or participants are required or needed. Also, it is of value that the review can be carried out at any time in the process and is not dependent on a given time frame (Wilson, 2013). Both of these advantages are very important when looking at the nature of this graduation research. At the same time this validation method also has weaknesses, namely the chance that single reviewers may overlook certain aspects or problems or perhaps generate false positives (Wilson, 2013). However, in this research the choice was made to have the review carried out by the entire IPM-team, therefore this disadvantage is negated for this particular research because the process model is reviewed by several and different disciplines.

The bottlenecks identified earlier in this research with the aid of the case study; project assignment 2018, are central during this validation. The bottlenecks which are specific related to maintenance projects, relate to the followings aspects; bureaucracy, terminology, role division, external stakeholders, V&V paragraph, V&V concerning the customer, V&V concerning the system, design process and analyze the project assignment. The aim of this research was to eliminate all these bottlenecks, the check whether this goal was actually achieved by creating the process model can thus be determined based on the extent to which the bottlenecks have been eliminated.

The validation will thus consist of a **checklist** of all bottlenecks, whereby a certain weighting is assigned to each bottleneck, resulting in a certain score. All of this can be seen, in an example of the validation checklist completed by the technical manager, in figure 5.1. The score, thus the validation, has succeeded when at least the six most important bottlenecks have been eliminated and when the end score is higher than an eight. This validation checklist will be gone through by each IPM-team member, it may be possible that a number of bottlenecks do not apply to the relevant process steps of a certain IPM discipline (for example, when looking at figure 5.1, the maintenance bottleneck related to external stakeholders is not the responsibility of technical manager and also not related to any activities of the technical manager). In these cases, these bottlenecks will have no influence on the score, but must certainly be covered and checked in the process steps where the other IPM disciplines are responsible for, so that in the end all bottlenecks are checked and actually are validated.

Six of the nine identified bottleneck related to maintenance projects are directly assigned to a specific process step and often have mutual relationships, these six **maintenance bottlenecks** are experienced as the most important. This was also evident from the prioritization by the SE- and IPM-team of these bottlenecks. This is the reason that these bottlenecks ultimately weigh more heavily in the validation process, the elimination of these six bottlenecks is more important and will therefore weigh more than the other three maintenance bottlenecks (for example, when looking at figure 5.1, it can be seen that the bottleneck related to designing weighs twice as much as the bottleneck with regard to the role division of the IPM-team).

The bottlenecks that relate to both construction and maintenance projects, thus the process description SE in general, are also included in the validation checklist. No weighting in attached to these **construction and maintenance bottlenecks**, only a few bonus points, since the elimination of these bottlenecks is not within the scope of this research (these bottlenecks are shown in the bottom table in figure 5.1). However, these bottlenecks have been kept in mind during the design and implementation of the process model and it would be a nice bonus if the process model could also indirectly eliminate these general bottlenecks.

Technical manager: *Youssef Hsaini*

Maintenance bottlenecks	Check	Weight	Score
Bureaucracy	☑	x1	*1*
Terminology	☑	x1	*1*
Role division	☑	x1	*1*
~~External stakeholders~~	☐	x2	*n.v.t.*
V&V paragraph	☑	x2	*2*
~~V&V customer~~	☐	x2	*n.v.t.*
V&V system	☑	x2	*2*
Design	☑	x2	*2*
Analyze project assignment	☑	x2	*2*
			Max. score: *11*
			Score: *11*
			End score: *10*

Bonus:

Construction & maintenance bottlenecks	Check
V&V	☑
Three specifications	☑
'Checking' process steps	☑
General design process description	☑

In other words: has this product become what the IPM-team wanted and needed?
Yes / ~~no~~

Figure 5.1: Example of validation checklist process model

The validation of the process model is carried out with the aid of an IPM-team, because the IPM-team ultimately has to actually use the process model. Because this same IPM-team was also involved in the previous process of identifying the bottlenecks, with the aid of the case study **project assignment 2018**, it is important that for this validation another case study is used to keep the validation as reliable and objective as possible. Therefore, the validation will be carried out by the same IPM-team, but on the basis of another case, namely the **project assignment 2019**. As a result, the process model will not only be validated in terms of eliminating the bottlenecks and thus the intended use, but also whether the process model, besides the project assignment 2018, also actually applies to other maintenance projects from the production line B of Rijkswaterstaat.

During the actual execution of this validation process, a difficulty has been experienced, namely the absence of the environmental manager from the relevant IPM-team. The environmental manager, who was involved in the process of identifying the bottlenecks and verifying the process model, is no longer working at Rijkswaterstaat, therefore this environmental manager was no longer available for the final validation of the process model. The relevant IPM-team has not yet appointed a new environmental manager who could possibly take over and carry out the validation. However, it is important that all process steps, including those for which the environmental manager is primarily responsible, are validated. The absence of an environmental manager was solved and guaranteed by having the SE advisor of the relevant IPM-team carry out an overall validation. This SE advisor has, in contrast to all the IPM-team members, validated all the process steps and thus the entire process model, instead of only a selection of responsible process steps per IPM discipline. Through the validation of the entire process model, the process steps relating to the environmental manager have therefore also been explicitly validated and the quality of the validation is retained and guaranteed.

The **results** of the validations must be analyzed, this has been done for each checklist, but for clarification, one of the checklists is explained in more detail below, namely the checklist that has been completed by the technical manager (figure 5.1). The figure shows that two of the maintenance bottlenecks are not applicable for the technical manager, thus these bottlenecks do not affect the score. In addition, all the maintenance bottlenecks that weigh more heavily are eliminated, this is minimally necessary for a successful validation. Also, all the other maintenance bottlenecks have also been removed, this ensures that the validation is successful because the score also need to be higher than an eight, this is satisfied because the final score is a ten. Even the bottlenecks that apply to both construction and maintenance projects are also eliminated. All in all, this ensures that the process model indeed became the product what the IPM-team wanted and needed.

This checklist, and the other checklists, with bottlenecks for the validation of the process model per IPM-team member, including results, has been added in appendix VII. The overall results show that the **validation** has been **successful**, not only the six most important bottlenecks have been eliminated in all cases, but also the remaining maintenance bottlenecks are eliminated and the score is in all cases higher than an eight. Even the general bottlenecks are indirectly included in the process model, which has ensured that these bottlenecks have also been eliminated. In conclusion, each IPM-team member, including the SE advisor, has indicated and confirmed that the process model actually became the product what they wanted and deemed necessary.

The process model is even applied from now on in the ongoing maintenance projects of the relevant IPM-team. However, both the SE- and IPM-team have pronounced that it would be desirable if research will be carried out in the future, into how the process model, in addition to the Western Netherlands South region, can also be applied in the other regions and possibly the other maintenance production lines of Rijkswaterstaat. This would benefit the uniformity and efficiency of the application of the process model itself and therefore also SE in general.

5.4 Results

The final results of the process model are added in appendix VI. The results are presented in the form of a lay-on note for the existing process description SE. Per process step the results are shown, not only shown but each result is also described in detail and has been extensively substantiated. In this paragraph, the results of the process model will be analyzed and described at various levels.

Results per process step

The modifications made in the process model per process step are so different and varying, that the results are difficult to compare or summarize. Therefore, for the results per process step, the entire process model must be considered (appendix VI). However, one or more maintenance specific bottlenecks have been eliminated in each process step by adding clarifications, additions or exceptions (not applicable). Thus, all process steps together eliminate all the identified maintenance bottlenecks related to bureaucracy, terminology, role division, stakeholders, V&V, designing and the project assignment.

Results per main process

Multiple process steps together form a main process, the process model consists of four main processes, namely structuring the project, analyzing and determining the customer requirements, designing and specifying the system specification and the elaboration of the contract specification. For each main process of the process model is shown how many clarifications, additions or exceptions (not applicable) have been added and described in the process model, the results of these are shown in table 5.5

Table 5.5: Overview of modifications in process model

Process model	Clarification	Addition	Not applicable
Structuring the project	12	6	0
Analyzing and determining the customer requirements	11	4	3
Designing and specifying the system specification	11	3	7
Elaboration of the contract specification	6	3	1
Total	**40**	**16**	**11**

Remarkable in the first main process '**structuring the project**' is that nothing from the current process description of this main process for construction projects is not applicable for this main process in maintenance projects (table 5.5). this means that in this main process no specific differences are actually present in the application of SE in construction and maintenance projects. The only modifications made in this main process are clarifications and small additions, these mainly relate to the awareness of the influence of these process steps on the further process. This main process mainly serves as an important basis and preparation for the execution of 'real' SE, which is actually carried out in the two following main processes. The awareness of the importance of this main process as preparation has been created by implementing the theory of SE with maintenance specific and practical examples.

In the second and following main process '**analyzing and determining the customer requirements**', clear differences between construction and maintenance projects become visible. These differences mainly relate to the stakeholders involved per project and therefore have a major influence on the application of SE. The stakeholders differ greatly in terms of quantity, involvement and risks between construction and maintenance projects, as a result of this some clarifications or exceptions (not applicable) are described in detail which identify, analyze and describe these differences in order to make clear what is, or is not, applicable for maintenance projects and to what extent certain activities must be carried out. Also in this main process, mainly clarifications were added in the process model (table 5.5). Mainly in order to create awareness that the process steps, despite some differences in construction and maintenance projects, are all important and need, to a greater or lesser extent, to be executed.

Most of the modifications, relative to the current process description, have been made in the third main process '**designing and specifying the system specification**' (table 5.5). These modifications mainly relate to the design process. Due to the differences in abstraction level and design flexibility between construction and maintenance projects, the illusion arose that the design process cannot and does not have to be completed in maintenance projects, but this illusion is incorrect. Therefore, most of the clarifications, additions or exceptions (not applicable) described in this main process relate to the awareness and clarification of the design process in maintenance projects. It has been explained that, despite the fact that some activities do not apply and some do apply but at a different abstraction level, roughly the same activities need to be carried out. In this main process it is also mainly about creating awareness about the fact that the design process also applies, to a greater or lesser extent, to maintenance projects. This awareness is created by translating the SE theory into practical and maintenance specific examples.

In the final main process '**elaboration of the contract specification**', in relative terms, the least modifications have been made (table 5.5). This is due to the fact, as mentioned earlier, that 'real' SE has already been implemented and executed in the two previous main processes and therefore this main process only serves as an important merger and conclusion of all the executed processes. The activities in this main process can be applied to both construction and maintenance projects, but in some cases the details have been clarified or a small addition or exception has been implemented. All these modifications in this main process relate to the contract types that need to be applied specifically in maintenance projects, instead of specific contract types for construction projects. Therefore, the activities to be carried out remain roughly the same, but the content is made specific and practical for maintenance projects, so that the process model becomes recognizable and easier to apply in maintenance projects.

Overall results (Rijkswaterstaat)

As can be seen in table 5.5, a total of 40 clarifications, 16 additions and 11 exceptions (not applicable) have been added to the process model. At one glance it becomes clear that the most modifications consists of clarifications, this shows that basically the same SE theory is applicable in both construction and maintenance projects. But that mainly difficulties and bottlenecks are experienced with recognizing or converting this SE theory into practice in maintenance projects. Therefore, the clarifications mainly consist of practical and maintenance specific examples in order to create awareness and recognition of the SE theory in maintenance projects.

Overall results (general)

Not only for Rijkswaterstaat, but also in general for other organizations in the civil engineering sector, often the SE theory is applicable for both construction and maintenance projects, with some small exceptions left behind. Therefore, it is important that if differences exist between construction and maintenance projects, these are identified and analyzed, in order to be able to describe what impact these differences have on the application of SE. This impact is rarely large enough that an addition or an exception must be made, but often does not mean more than a clarification of the same applicable SE theory. Therefore, the clarifications mainly need to be practical and maintenance-oriented examples, to create awareness and recognition of, more or less, the same applicable SE theory in maintenance projects as in construction projects.

6. Information model

This chapter focuses on the second model of this research, namely the information model. The information model is a derivative of the process model and applies to the element ‘measure’. First of all, the design of the information model is described, then the model is actually implemented and finally validated.

6.1 Model design

The first and main model of this research, the process model, eliminated all identified bottlenecks related to maintenance projects in the existing process description and ensured that the process description is now also applicable for major infrastructure maintenance projects. The second model of this research, an **information model**, is a derivative of the first model, consciously chosen to go deeper into one of the previously identified bottlenecks in order to create extra depth in this research.

It was decided to go deeper into the first process step of the process description, namely the analysis of the project assignment (P1), this process step was chosen because according to the SE work field the most difficulties are found in this process step in practice. These difficulties are mainly about the maintenance aspect '**measure**', which is used within Rijkswaterstaat to express the activities related to variable maintenance. All activities that need to be carried out for this advice together form a list of measures (in Dutch better known as RUPS). Based on this list of measures, the regions within Rijkswaterstaat draw up the regional programming, also known as the project assignment, thus process step P1.

The starting point for the emergence of a measure is that some **damage** has been identified. Damage can negatively affect the safety, comfort and accessibility of the road users and therefore maintenance must be carried out to deal with the damage. The selection of the right measures is influenced by inventory and assessing all the damage through visual inspections and measurements. If these damages exceed a certain intervention level, maintenance must be carried out to address these damages. Using maintenance- and policy-guidelines, possible measures are selected, of which ultimately the optimum measure is selected per damage.

In practice, difficulties are encountered with these maintenance measures, not only due to the fact that these measures differ per region of Rijkswaterstaat, limit the design flexibility and therefore have a major influence on the solution, but difficulties are mainly experienced by the fact that it is still unknown how the 'measure' element relates to all the other information elements in maintenance projects. Identifying and establishing the coherence and relationships between the various elements in maintenance projects is important in order to manage the all the project information in a correct and structured manner, certainly from the point of view of SE.

Within Rijkswaterstaat, all project information, including all related elements and information models, is organized using GRIP. GRIP is a **digital project environment** established in Relatics, especially for Rijkswaterstaat. Therefore, it is important that an information model for the element measure will be created, fits in with the already existing information models and can therefore be included in the existing digital project environment of Rijkswaterstaat. An information model represents the characteristics and mutual relations of various elements in which the measure element is central. The content of an information model can be modeled using a modeling language, with the aid of this modeling language the information model can later be translated into a digital model. Therefore, the second model of this research becomes an **information model**. The information model is of added value because this will be the input for a digital model (in GRIP), so that in the near future all information and related elements, including the measure element, in maintenance projects can be managed in a complete, effective and efficient way.

The design of the information model has already been largely influenced and determined. This is due to the fact that this research is carried out for and in collaboration with Rijkswaterstaat, which means that the information model for the measure element must be in line with the already existing information models of Rijkswaterstaat. As a result, the information model can be more easily implemented in the digital project environment of Rijkswaterstaat at a later time. Therefore, it is important that the same modeling language is used, the modeling language that Rijkswaterstaat uses for this purpose is **Unified Modeling Language** (UML), which will also be used for creating this information model. In addition, it is also important that if the measure element is associated with already existing elements, these will be reused and applied in the right and existing way so that the larger whole is also connected and coherent with the existing information models of Rijkswaterstaat.

6.2 Model implementation

The substance of the **information model** is created through the application of the **MBSE** method. MBSE is the formalized application of modeling, the creation of models to exchange information is the primary goal of this method (Lockheed Martin, 2015). As mentioned earlier, an MBSE information model can be modeled using a modeling language, one of the most well known and used modeling language, similarly within Rijkswaterstaat, is **UML**. In this research, the tool used to develop the UML information model is **Visio**, this was chosen because the already existing information models of Rijkswaterstaat were also modeled in Visio and this tool was made available for use. Through applying the same modeling language (UML) and modeling tool (Visio), the final information model can easily be translated and implemented into a digital model and the already existing digital information management system of Rijkswaterstaat. All the necessary choices made above, with regard to the design and implementation of the information model, are clearly arranged and shown in the figure below.

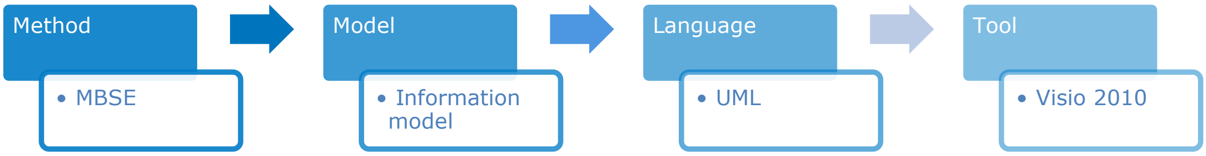


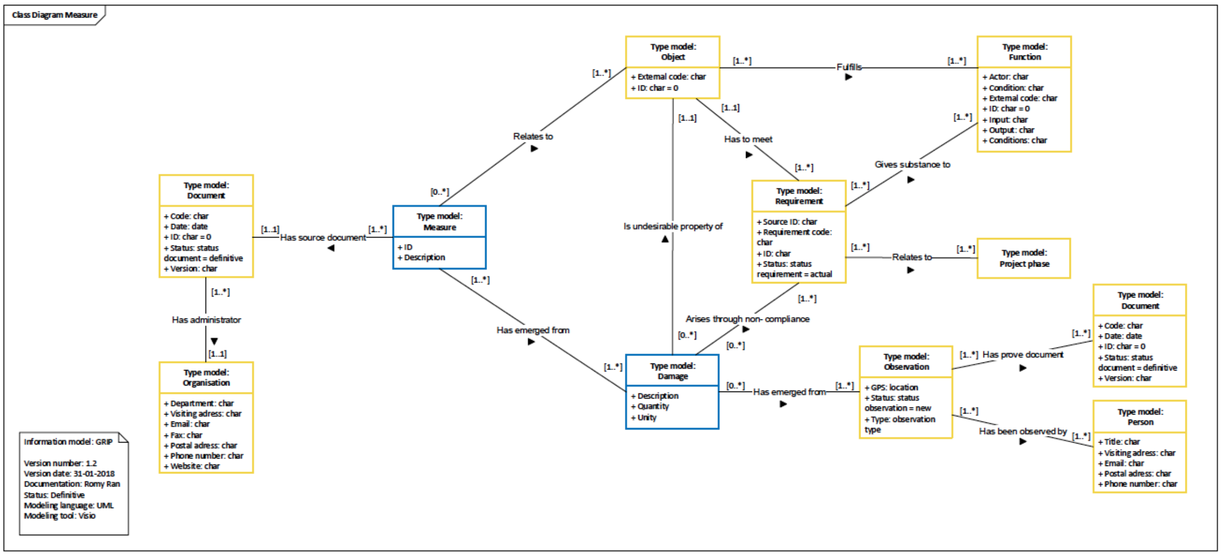
Figure 6.1: Implementation information model

6.2.1 Class diagram

In order to create an information model, it is necessary to know what an information model usually consists of. The different elements of an information model are called class diagrams. Each class diagram has a class diagram name, this is the definition of the relevant element type. A class diagram can consist in its turn of attributes, these attributes represent values that a class diagram can be recognized on and should consist of (Booch, 1997). The different class diagrams in the information model can have different types of relations with each other, connecting lines represents these relationships. A connection line, on its turn, may consist of an explanation of the relationships and any notation(s) (Booch, 1997). The explanation of a connection line can be supported by the use of an arrow, this indicated the reading direction of the explanation of the relation and thus supports the user-friendliness of the information model. However, it is important that despite the reading direction the relationship must always apply from both directions. The notations show how often a relationship can occur, an example of this is the notation [1..*], this means that the relationship always occurs at least once, but it is possible that this relationship also can occur more often.

Now that it is known what an information model can consist of, substance can be given to the information model. First of all, research was done into what a ‘measure’ exactly is and how it relates to other and different elements, consulting various sources from the used maintenance case study projects has overtaken this. By asking questions such as, ‘how does a measure arise’, ‘what does a measure relate to’, ‘when does it apply’ and ‘in what way is a measure selected’, the most important related elements come forward and become visible.

Ultimately, with all the above information, the final information model was drawn up, consisting of various class diagrams, attributes, multiplicity relations and notations. This information model, also called class diagram measure, is shown in figure 6.2 and is also added in appendix VII on a larger scale. Figure 6.2, a clear distinction is made in this information model between the newly added class diagrams and the already existing class diagrams. The class diagrams that are outlined in blue are the newly created class diagrams, the yellow outlined class diagrams are already existing class diagrams from information models of the digital information management system of Rijkswaterstaat.



Legend

- Added class diagrams
- Existing class diagrams
- — Relations between class diagrams

Figure 6.2: Information model

After all the relevant class diagrams were identified, a distinction was thus made between new and existing class diagrams. During the design and implementation of the information model, as much as possible has been tried to use existing class diagrams from the digital information management system of Rijkswaterstaat, this was deliberately chosen to ensure an ultimately easier and better connection and application of this information model with the already existing information models of Rijkswaterstaat, because the already existing class diagrams are implemented in the same way, so that the information model can seamlessly fit in within the existing digital information management system of Rijkswaterstaat. Despite the fact that as much as possible has been tried to implement existing class diagram, two new class diagrams were needed to be drawn up and added. An overview of both these new and existing diagrams is shown in table 6.1 below.

Table 6.1: Overview of class diagrams

Overview of class diagrams	
Added class diagrams	**Existing class diagrams**
Measure	Object
Damage	Function
	Requirement
	Project phase
	Observation
	Person
	Document
	Organization

Added class diagrams

In the information model, two new class diagrams have been drawn up and added, namely the class diagrams measure and damage. The measure element is missing in GRIP, the digital information management system (Relatics) of Rijkswaterstaat, which causes that IPM-teams of maintenance projects cannot manage their information effectively and efficiently. Therefore, the missing measure element is the cause of the design and implementation of this information model.

Figure 6.3 shows the newly added class diagram of a **measure**. The class diagram consists of two attributes, namely ID and description, this is based on the results of the executed document analysis of the two case studies consulted in this research. The attribute ID stands for the ID number of a measure, every measure is indicated with an identical ID number within Rijkswaterstaat. Therefore it is important that a measure consists of an ID. The second attribute is description, in which a measure is described in a specific activity that needs to be performed. An example of a description of a measure can be 'the roughening, blasting and sanding of the coating'. A measure is always related and resulted from an observed damage. In the case of the foregoing example, skid resistance was observed as damage, as a result that the coating need to be roughened, blasted and sanded. Concluding, a measure within Rijkswaterstaat always consists of, at least, an ID number and a description.

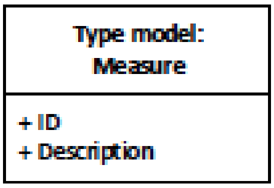


Figure 6.3: Class diagram measure

As mentioned above, the starting point for the emergence of a measure is that damage has been identified. However, the class diagrams for damage did not yet exist within the already existing information models of Rijkswaterstaat. Therefore it is of great importance that this class diagram will be created and added, because damage ensures the existence of a measure and need to be properly assessed in order to ultimately select the most appropriate measure. The damage class diagram consists of three attributes, namely description, quantity and unity (figure 6.4). Damage must always be described in a description, these so called damage descriptions are extensive description of, for example, rutting, skidding or cracking of the road surface. It is also necessary that the quantity and unity of the relevant damage be known, for example, 500 m^2. This is important in order to be able to make an estimate of the extent and severity of the damage, the activities that need to be carried out and to calculate the associated costs. All in all, within Rijkswaterstaat, damage must always consists of at least a description, quantity and unity.

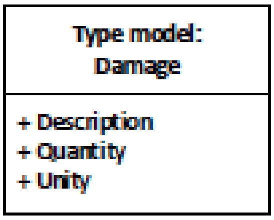


Figure 6.4: Class diagram damage

Existing class diagrams

The remaining class diagrams in the information model, in addition to the newly added class diagrams measure and damage, are also considered as necessary, but these class diagrams already exist in the existing information models of Rijkswaterstaat. These existing class diagrams relate to the following elements, namely object, function, requirement, project phase, observation, person, document and organization. These class diagrams are considered as necessary for this information model and thus taken over from the existing information models of Rijkswaterstaat to ensure the best possible connection and implementation of this information model within the already existing digital information management system of Rijkswaterstaat (GRIP in Relatics) and by the fact that a whole team of specialists has already thought this through. Despite the fact that these class diagrams already exist, they are still briefly explained below.

Already known is, how a measure has arisen, namely by observing a damage. Therefore, observing damage is an important part of the realization of a measure. The class diagram **observation** is therefore found necessary to include in this information model. According to Rijkswaterstaat, an observation always consists of a GPS location, status and type of observation.

Based on the existing information models of Rijkswaterstaat, the class diagram observation was inextricably linked to two other important class diagrams, namely the class diagrams **document** and **person**. It is important that it is known by which person an observation was observed and that the relevant observation was also captured in a document, therefore these two existing class diagrams are also included in this information model.

It is now known that a measure has emerged from a damage, so ultimately an appropriate measure need to be selected on the basis of the damage. Each selected measure need to be captured in a **document**. This source document is, in the case of Rijkswaterstaat, a measure list. Every document in which measures have been described and captured must consist of an ID, code, status, date and version. It is important that this source document also has an administrator, this administrator must select the appropriate measures and capture these in this source document. Rijkswaterstaat manages all documents relating to projects within Rijkswaterstaat, in other words, an **organization** is the administrator of a document. Therefore, the class diagram organization is important, necessary and also included in the information model.

A measure as well as a damage, both apply to an **object**. Damage is in fact an undesirable property of an object and a measure that has to be executed relates to this same object. From the existing information models of Rijkswaterstaat, the class diagram object was inextricably linked to two other important class diagrams, namely the class diagrams **function** and **requirement**. This is due the fact that an object fulfills a function and this object must also meet all requirements, that in its turn give substance to the concerned function. The class diagram requirement is of great importance within this information model because it is only possible to examine whether or not an object meets the relevant requirements, by imposing requirements on an object. As a result, damage can be observed, because damage occurs by not meeting the requirements that relate to a specific object that has to fulfill a certain function. These three class diagrams, object, function and requirement, are therefore inextricably linked to the class diagrams measure and damage. Therefore, it has been found important and necessary to include these class diagrams in the relevant information model.

Finally, the class diagrams **project phase** has been added to the information model, which is important for the context of this information model and research. This important aspect has been incorporated in the information model by establishing a relationship between a requirement and a project phase, because a measure only occurs during maintenance phases, therefore the appropriate requirements need to be selected in the appropriate project phase.

Relations

The relations between the different class diagrams are important to ensure the usability and readability of the information model. As mentioned earlier, a relation usually consists of an explanation including reading direction and notations. The relations between the class diagrams in the information model are cut up in smaller parts, in this case in five parts, in order to clearly explain all the different relations one by one. First, the relation between the two newly added class diagrams, namely a measure and a damage, will be discussed. Subsequently, the relations between these newly added class diagrams in relation to the already existing class diagrams would be also discussed. Eventually, all relations from the information model will be briefly explained below.

Figure 6.5 shows the relation between a **measure** and a **damage**, it shows that a measure has occurred from a damage. The notation [1..*] makes clear that a measure has always originated from at least one damage, but can also result from multiple, even infinitely, damages. This relation must also be readable in the opposite direction, so a damage is the cause for the emerge and drafting of a measure. If a damage has been observed, this damage at least relates to one measure, but this damage can also be included in several measures.

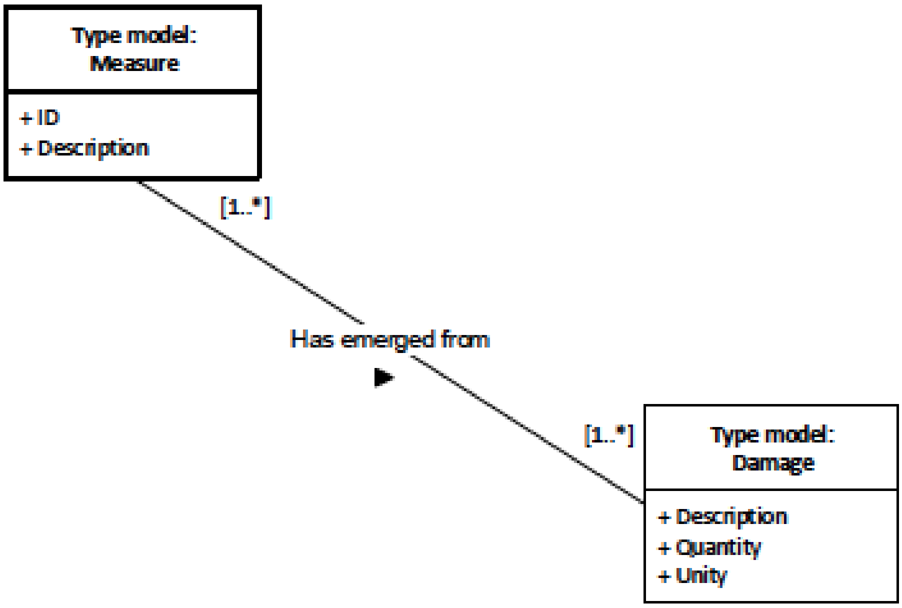


Figure 6.5: Relation between measure and damage

As can be seen in figure 6.6, damage can be observed by at least one, but also by several observations. In the opposite direction, this relation is different, since a observation does not always necessarily have to lead to finding some damage, but it can possibly can also lead to an observation of one or more damages. An observation always has one or more proof documents, the amount of these proof documents depends on the amount and types of observations. Also, an observation must always be carried out by one or more persons, conversely, a person can also conduct one or more observations.

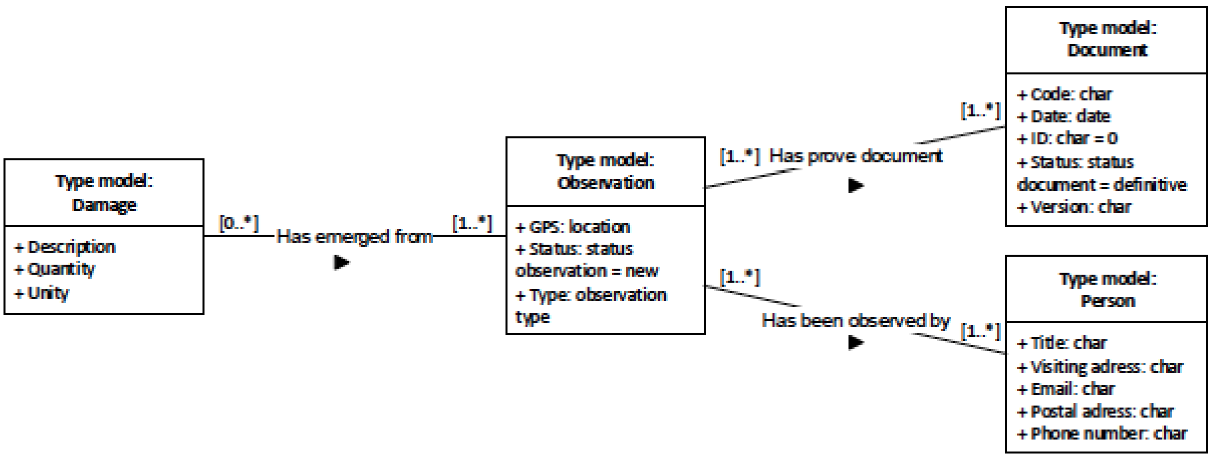


Figure 6.6: Relation between damage, observation, document and person

As mentioned earlier, a measure always has a source document, in the case of Rijkswaterstaat this is the so called measure list. This document is an important document because it is part of the project assignment of maintenance projects. Therefore, for each maintenance project, only one measure list is drawn up, this can also been seen in the relation between a measure and a document (figure 6.7). in the opposite direction, a source document can contain several measures, namely all selected measures for the entire maintenance projects. This document always has only one administrator, namely the organization, in this case this is Rijkswaterstaat. But, in the opposite direction, an organization can be the administrator of one or even more documents.

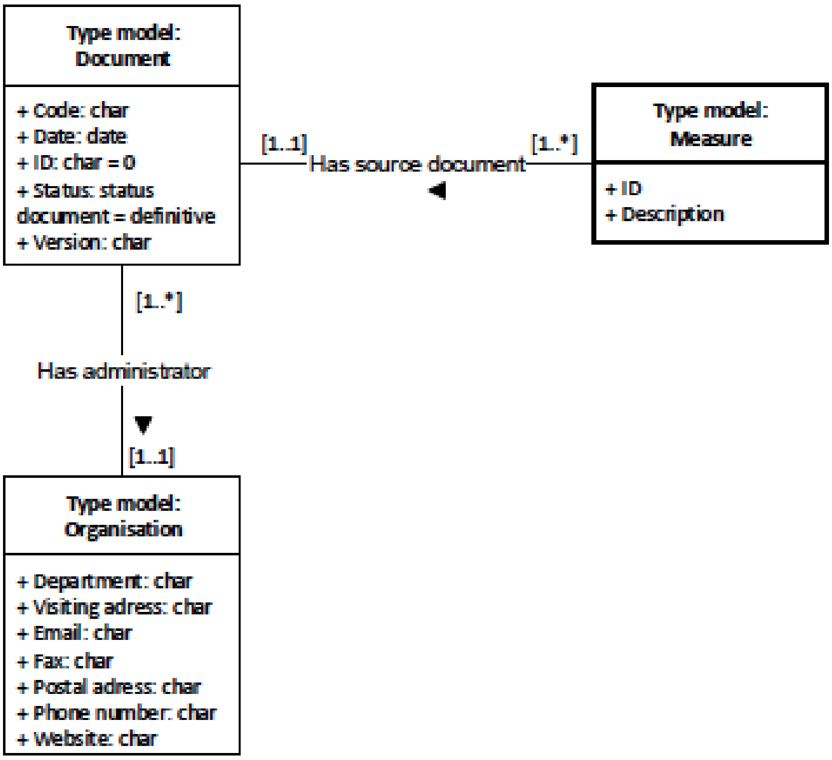


Figure 6.7: Relation between measure, document and organization

In figure 6.8 can be seen that both a measure and a damage have a relation with an object. A measure always relates to at least one object, but can also relate to multiple objects, while an object does not always have to be assigned to a measure. In contrast to a measure, a damage always relate to only one object, this is because a damage is an undesirable property of a specific object. Conversely, an object does not always have to have any damage, but can instead consist of infinite damage. It is also important that an object meets requirements, so that an object can fulfill a certain function. Damage to an object is therefore caused by failure to comply with a requirement of the relevant object, as a result of which the object cannot properly fulfill a function.

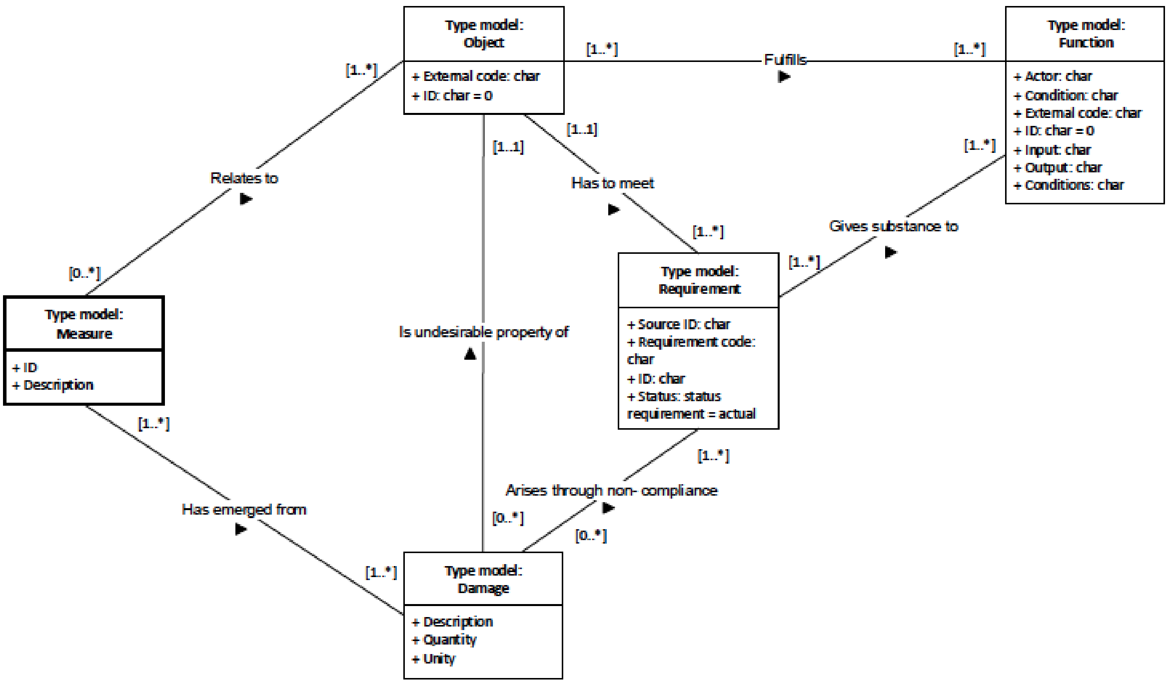


Figure 6.8: Relation between measure, damage, object, requirement and function

The last important relation relates to the class diagram project phase. A requirement, that an object must satisfy in order to fulfill a function, always relates to a specific project phase. An object usually consists of many different requirements, these requirements can therefore also relate to different project phases (figure 6.9). It is important that the requirements are related to a certain project phase, in order to be able to check whether or not an object meets the requirements in that particular project phase. In the case of a measure, which only occurs in maintenance phases, a requirement must therefore be related to at least the maintenance phase.

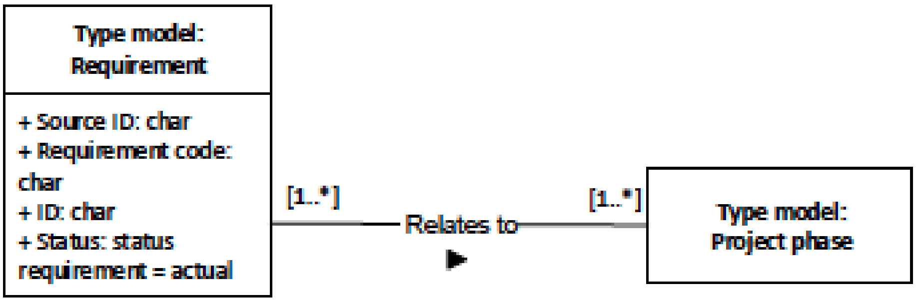


Figure 6.9: Relation between requirement and project phase

All in all, it is now known and clear how a measure first of all arises (due to a damage, figure 6.5), how a damage in its turn is observed (figure 6.6), how a measure is subsequently captured (figure 6.7), what a measure relates to (an object, figure 6.8) and finally in which project phase a measure applies (figure 6.9).

6.2.2 Verification

In order to test the substantive quality of the information model, verification has been carried out. During the verification, attention was paid to the correct application of UML, its connection to the already existing information models, the relevance of the scope of the information model and finally the connection of the specifications of maintenance projects, in which measures play an important and central role. The verification was carried out by a SE advisor, who is also the administrator of all the existing information models of Rijkswaterstaat, which are the input for the digital information management system in GRIP. Some small suggestions for improvements arose from the verification, which did not relate to the quality of the content but only were related to the layout and thus user-friendliness of the information model. These suggestions for improvements were taken into account and included in the information model. As a result of the verification, the quality of the information model has, where necessary, been improved and has been guaranteed.

6.3 Model validation

In the previous section, the information model was verified, which guarantees the substantive quality of the information model and, where necessary, improved. The verification was the **check if it is done right**, but the validation still has to **check if the right thing is done**, this difference is important and essential. Validation should be conducted into whether the information model can actually be translated into a digital model and thus is the desired and needed input. So that it can ultimately be implemented within the already existing digital information management system of Rijkswaterstaat, which ensures that in the future maintenance projects can also be managed in GRIP.

The validation of the information model was carried out by an information specialist from the GRIP-team of Rijkswaterstaat, this is the person who can confirm if the information model is actually the right input for the digital information management system and can solve the problem of the missing measure element in **GRIP**. Within Rijkswaterstaat, the validation of an information model is always carried out in two ways, the so-called ‘example validation’ and ‘triangle validation’. If both validations are properly executed and met, the information model meets all the requirements for being able to be translated into a digital model and therefore to be included in the digital information management system of Rijkswaterstaat, in order to also manage maintenance projects in GRIP in the future.

The first, so-called ‘**example validation**’, is a validation in which each class diagram in the information model is interpreted using an example from practice. By assigning practical examples to all class diagrams, all relationships in the information model can be easily tested, which is of great importance for the eventual implementation of the information model into a digital model, because the digital information management system can only function properly if all relationships are actually modeled as they occur in practice. So, by assigning practical examples to all class diagrams, in this case examples from a maintenance project, the information model can be validated.

This example validation has been applied and implemented for the entire information model, the elaboration of this can be found in appendix VII. However, for purposes of illustration and clarification, a part of the information model is explained below and is shown in figure 6.10. In this figure, it can be seen that a damage has been signaled, it originated from an observation. The class diagram of this observation can be translated into an example such as, in this case, visual inspections. Because of these visual inspections, the damage, namely insufficient skid resistance, has been observed. The visual inspections have been observed by a person, in this case by Jean Luc Beguin. The observation, in this example the visual inspections, are included and recorded in a prove document. The class diagram document is therefore also made practical using the example of a damage assessment document. Finally, the damage affects the type of measure that is selected to ultimately eliminate this damage. In this case the measure ‘conserve coating’ is prescribed for the damage of insufficient skid resistance. This example validation is thus carried out in this way for the entire information model (appendix VII) and is, according to the information specialist from the GRIP-team, successful.

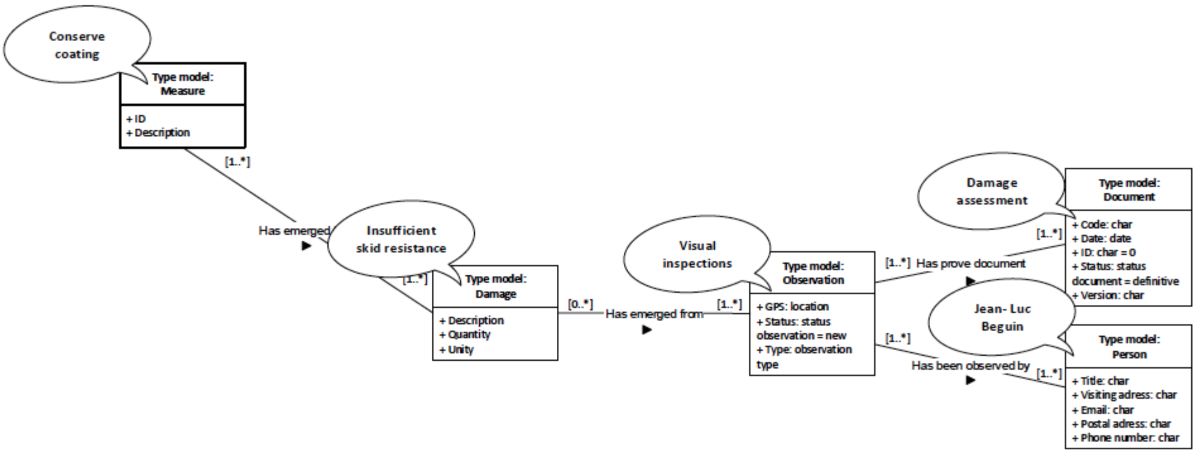


Figure 6.10: Example validation of information model

The second validation, the so-called ‘**triangle validation**’, is a second check, on top of the previously performed validation. During this validation is not looked at the entire information model, but only to the so-called triangles, these triangles do not always have to be present in an information model. However, in this information model, two triangles are present. These triangles arise if three class diagrams form a closed relationship within the entire diagram, this can be recognized by the shape of a closed triangle. The two triangles in this information model are object-requirement-damage and object-damage-measure. Due to the closed construction of these triangles, mutual multiplicity relationships are difficult to understand and translate into practice, therefore it is important that these relationships are modeled correctly so that they can function properly in the digital information management system. This validation has also been carried out by the information specialist from the GRIP-team and has been successful. Therefore, it can be concluded that the information model meets all the requirements for being able to be translated into a digital model at a later time and can also be implemented in the digital information managements system, so that maintenance projects can also be managed in GRIP in the future.

7. Conclusions & recommendations

In this last chapter, the final conclusions and recommendations of this research will be described. The conclusions are subdivided into generally applicable conclusions and conclusions that are specifically applicable to Rijkswaterstaat. This final chapter ends with some recommendations for future research and development.

7.1 Conclusions

The purpose of the conclusion is to answer the main question of the research. In this research, the main question can be answered from two different perspectives, namely a conclusion that is generally applicable and a conclusion that specifically applies to Rijkswaterstaat. The main question of this research has been repeated and is shown below.

“How can the application of Systems Engineering make
major infrastructure maintenance projects more effective and efficient?”

7.1.1 General

Both theory and practice show that the application of Systems Engineering (SE) in construction projects is of added value and ensures greater effectiveness and efficiency. However, the use of SE in major maintenance projects is still unknown and therefore **difficulties** are encountered to implement SE within these maintenance projects. This is caused by, among other things, the different contract types that apply to construction and maintenance projects. Due to the presence of these different contract types, it is often unclear and unknown to what extent the scope and abstraction level of maintenance projects should be specified.

“Which general principles of Systems Engineering are applied in
major infrastructure maintenance projects?”

First of all, the **general principles of SE**, which are applicable to both construction and maintenance projects, have been investigated and determined. The literature shows that the application of five general principles can ensure the successful application of SE. All these principles are equally important and are related to each other, the five general principles of SE are as follows; systems thinking, integral approach, customer management, design flexibility and requirements management.

“What are the differences between construction and
maintenance infrastructure projects?”

Subsequently, the **differences between construction and maintenance projects** were examined, in order to eventually find out why the application of SE in maintenance projects is still unexplored area. The characteristics of construction and maintenance projects to which these can be compared and which also relate to the field of SE are as follows; contract types, scope, stakeholders, abstraction level, design flexibility and project phases. Based on these characteristics, differences are found between construction and maintenance project. These differences are mostly large and immediately visible, for example when looking at the scope of the project. In construction projects the scope is large and new, while the scope in maintenance projects is relatively small and already existing, which is an important risk in maintenance projects. The differences are also very clear with regard to the stakeholders. In construction projects many, both internal and external, stakeholders are involved and are often still unknown, this is an important risk in construction projects. While in maintenance projects a clear and small number of mostly internal stakeholders are involved. The last difference in contract types is also immediately clear, for construction projects the contract types D&B and DBFM are applied, while in maintenance projects the performance contract and E&C contract are applied. It was expected that all the differences between these two processes would be major, but above expectations some differences are not even so different up to a certain level. Despite the identified differences in all characteristics, construction and maintenance projects both roughly go through the same project phases and associated activities, this, as well as the design process and activities of specifying, are to a certain level very similar and remain more or less the same.

“Which bottlenecks can be identified in the way Systems Engineering is applied in major infrastructure maintenance projects?”

Various **bottlenecks** have been identified with the aid of a case study of a maintenance project of Rijkswaterstaat. Despite the fact that these bottlenecks are specifically applicable to Rijkswaterstaat, some of these bottlenecks can also be approached in general, because these bottlenecks can be directly assigned to and derived from the general principles of SE, which are always applicable and can therefore occur in any environment. These bottlenecks, or difficulties experiences with regard to the application of SE in maintenance projects, relate to stakeholders management, verification and validation (V&V) and designing. The bottleneck with regard to stakeholder management can be related to the general principle of SE, namely customer management. The bottleneck concerning V&V is related to the general SE principle of requirement management and the last bottleneck of designing concerns design flexibility. These experienced bottlenecks can often be explained by the different characteristics of maintenance projects in contrast to construction projects, because the philosophy and theory of SE remains the same in both projects. However, in some cases, small changes, exceptions or additions are applicable for maintenance projects compared to construction projects.

The bottleneck with regard to **stakeholder management** arose because the stakeholders in maintenance projects (few, mainly internal, known) deviate a lot in comparison with the stakeholders in construction projects (many, both internal and external, unknown), but this does not actually affect the application of SE because the same principles of SE apply, only sometimes to a greater of lesser extent. The bottleneck with regard to **designing** concerns both the scope of the project and the abstraction level and associated design flexibility. In maintenance projects, there is the illusion that the design already exists and therefore no design choices can or have to be made. This assumption was created by the different scopes in construction and maintenance projects, because the scope in construction projects is mostly large and new and in maintenance projects relatively small and already existing. While in reality design choices are also made in maintenance projects, but only more often at a lower abstraction level and with limited design flexibility, making it more difficult to recognize these design choices. The last bottleneck, which related to **V&V**, is related to both previous bottlenecks. Difficulties with the application of V&V in maintenance projects have arisen due to the assumption that no design choices are made and also due to the involvement of a small number of mostly internal stakeholders, this created not only confusion in the application of V&V with regard to the activities to be carried out, but also with relation to the stakeholders.

“What improvements and advice can be given to make the application of Systems Engineering in major infrastructure maintenance projects more effective and efficient?”

The bottlenecks, which can be experienced in each project environment with regard to stakeholders management, V&V and designing, all relate to the general principles of SE. These SE principles are applicable for both construction and maintenance projects, but these bottlenecks are still experienced despite the fact that the same SE theory applies, to a greater or lesser extent. Thus, the **advice** to eliminate these bottlenecks relates to the translation of this SE theory into practical and maintenance-oriented examples, in order to create awareness that, for example despite a smaller number of stakeholders or making design choices at a lower abstraction level, the same general principles of SE are still applicable.

7.1.2 Rijkswaterstaat

Within Rijkswaterstaat **difficulties** are experienced with the application of SE in maintenance projects, this is caused by the process description SE, which is not yet fully applicable for maintenance projects but only for construction projects of Rijkswaterstaat. Within the IPM-teams, which actually apply the process description, there is often insufficient knowledge from SE to solve these difficulties themselves. As a result, that the final product of the process description (the contract specification, which outlines the client's question to potential contractors) often does not meet the desired and prescribed quality.

"Which general principles of Systems Engineering are applied in
major infrastructure maintenance projects?"

Firstly, it was investigated whether the **general principles of SE** that Rijkswaterstaat applies, actually correspond with the general principles of SE from the literature. This analysis shows that the general principles of SE of Rijkswaterstaat correspond with those from the literature, so this is not the cause of the experienced difficulties in maintenance projects.

"Which bottlenecks can be identified in the way Systems Engineering is applied in
major infrastructure maintenance projects?"

Subsequently, the **bottlenecks** of the application of the process description SE in maintenance projects of Rijkswaterstaat were identified with the aid of a case study. The identified bottlenecks relate to the following aspects; bureaucracy, terminology, division of roles, stakeholder management, V&V, designing and analyzing the project assignment. All these bottlenecks can be traced back to the general principles of SE and the differences between construction and maintenance projects.

"Which validation models (e.g. process model, information model) are suitable to verify the complete
and correct application of Systems Engineering in major infrastructure maintenance projects and
how can it be applied?"

In order to **solve** these bottlenecks, a lay-on note for the process description SE has been created which only applies to major infrastructure variable maintenance projects of Rijkswaterstaat. In this so-called **process model**, some changes, additions or exceptions to the current process description are described and substantiated with the aim to create awareness of the, more or less, same application of SE and to make this same SE theory more practical with the help of maintenance specific examples. The process model has now become the connecting factor and translation between the theoretical principles of SE and the practical maintenance projects, as a result that the previously identified bottlenecks have been eliminated. From now on the process model is consulted and used by the IPM-teams of Rijkswaterstaat in maintenance projects, so that these maintenance projects by means of the use of SE and the process model, can be carried out more effectively and efficiently.

To be able to carry out maintenance projects even more effective and efficient in the future, it is necessary that the information of maintenance projects can also be managed in the digital information management system (GRIP in Relatics) of Rijkswaterstaat. In order to be able to manage projects, it is necessary that information models be created for all the relevant and crucial information elements of a project. In this way, all information within a project can be processed, merged and managed. However, for maintenance projects the **information model** of an important maintenance element is missing, namely the element measure. Researched and recorded is what a measure actually is and how it relates to other elements in maintenance projects. Ultimately, an information model was created for the measure element, so that this information model can be translated into a digital model in the future and therefore can be included in the digital information management system, GRIP, of Rijkswaterstaat. With the aim that maintenance projects can be managed as well in the future, which increases effectiveness and efficiency.

7.2 Recommendations for future research

The recommendations are subdivided into recommendations for future research in theory and practice. The recommendations in theory relate to the research in a general and scientific way, while the recommendations in practice are specifically intended for Rijkswaterstaat.

The recommendations for future research in **theory** relates to the limited application of the case study method. Due to the nature and duration of this type of research, is deliberately chosen for a single case study. As this name implies, only one case study project and therefore also only one IPM-team within Rijkswaterstaat has been investigated to identify the bottlenecks in the application of the process description SE in maintenance projects. Therefore, it is advisable to consult multiple and several case studies in the future, also outside the organization of Rijkswaterstaat, to ensure that all bottlenecks are identified or perhaps to discover new or different potential bottlenecks.

The recommendations for future research in **practice** are specifically addressed to Rijkswaterstaat and are related to the two models that have been created and adapted to the processes and projects of Rijkswaterstaat, namely the process model and information model.

The first recommendation relates to the **process model**, the lay-on note for the process description SE that is specifically applicable for maintenance project within Rijkswaterstaat. The process model was drawn up with the help of a case study from the production line B and a well willing IPM-team from the Western Netherlands South region of Rijkswaterstaat. However, Rijkswaterstaat consists of several regions than just the West Netherlands South region, within these regions diversity in the application of SE and the process description may be possible. Therefore, it is advisable to implement and, if necessary, to adjust the process model in order to work in a more uniform, effective and efficient way throughout the entire organization of Rijkswaterstaat. Also, research can be carried out into the extension of the process model for B-roads to the other project in the production line B, such as B-bridges and B-waterways, this can probably be done relatively easily and quickly due to the many corresponding characteristics between the project in the same production line. Subsequently, possible research can be conducted in order to make the process model also applicable to all the production lines, A to D, within Rijkswaterstaat.

The second recommendation relates to the **information model** of the measure element. It is important that this information model is going to be translated into a digital model as quickly as possible, so that the digital model can ultimately be included in the digital information management system of Rijkswaterstaat. As a result, maintenance projects can be managed more effectively and efficiently in GRIP in the future.

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Appendixes

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Appendix I: Interview - Project manager

Algemene informatie	
Naam	Tohid Navabi
Functie	Project manager
Processtappen	P1
Project	GVO WNZ B-wegen; POF 2018
Datum	10-10-17
Plaats	Utrecht

Hoofdproces **Processtap**	Structureren project P1: Analyseren projectopdracht
Q1*	Ja, de project manager is hoofdverantwoordelijke voor deze processtap.
Q2*	Nee, het gestelde doel komt niet overeen met het doel van deze processtap voor onderhoudsprojecten. Het doel voor onderhoudsprojecten zou als volgt moeten zijn; Inzicht verkrijgen in de maakbaarheid en haalbaarheid van het project opdracht formulier (POF).
Q3*	In principe is dezelfde input nodig, namelijk een opdrachtbeschrijving. Echter wordt de opdrachtbeschrijving in aanlegprojecten en dus in de procesbeschrijving vorm gegeven door een scopeformulier en in onderhoudsprojecten wordt de opdrachtbeschrijving vorm gegeven in een project opdracht formulier (POF). In principe is dit dus hetzelfde maar heeft het alleen een andere naam, dit zorgt echter wel voor verwarring binnen onderhoudsprojecten wanneer zij de procesbeschrijving raadplegen.
Q4*	Hiervoor geldt hetzelfde antwoord wat gegeven is op de vorige vraag. In principe is dezelfde output gewenst, echter zorgt het begrip scopeformulier voor verwarring en zou dit POF moeten zijn in dit geval voor onderhoudsprojecten.
Q5*	De activiteiten die uitgevoerd moeten worden zijn in de huidige procesbeschrijving gebaseerd op de structuur en inhoud van een scopeformulier, dit zou voor onderhoudsprojecten moet worden gebaseerd op de structuur en inhoud van het POF. Dit zou de volgende activiteiten vereisen; het analyseren van de projectbeschrijving, budget, planning, omgevingsmanagement, publieksgericht netwerk management, risico's, informatie overdracht, proces afspraken en overige gegevens t.b.v. het uitvoeren van de opdracht.
Aanvullende opmerkingen	-

* In alle afgenomen interviews worden steeds vijf dezelfde vragen gesteld (Q1 t/m Q5). Deze vragen zijn al beschreven in paragraaf 4.2.2, maar worden hieronder nogmaals benoemd:

Q1: De procesbeschrijving SE schrijft voor dat de IPM-rolhouder als '…-manager' verantwoordelijk is voor deze processtap. Is dit ook daadwerkelijk het geval in de praktijk van dit project? Zo nee: welke IPM-rolhouder is dan verantwoordelijk?

Q2: Komt het doel van deze processtap (van de procesbeschrijving SE) overeen met het doel van deze processtap in dit project? Zo niet: wat zal dan het geschikte doel moeten zijn voor deze processtap?

Q3: Welke input is nodig om deze processtap uit te kunnen voeren? (Indien dit niet overeenkomt met de input volgens de procesbeschrijving SE: vraag dan waarom is gekozen om hiervan af te wijken)

Q4: Wat is de gewenste output om deze processtap te kunnen voltooien? (Indien dit niet overeenkomt met de output volgens de procesbeschrijving SE: vraag dan waarom is gekozen om hiervan af te wijken)

Q5: Welke specifieke activiteiten moeten tijdens deze processtap worden uitgevoerd? (Indien dit niet overeenkomt met de activiteiten volgens de procesbeschrijving SE: vraag dan waarom is gekozen om hiervan af te wijken)

Appendix II: Interview – Management project manager

Algemene informatie	
Naam	Ad van Ginneken
Functie	Manager project beheersing
Processtappen	P2, P3, P4, P6
Project	GVO WNZ B-wegen POF 2018
Datum	24-10-17
Plaats	Rotterdam

Hoofdproces **Processtap**	Structureren project P2: Structureren werkpakketten en producten
Q1	Ja, de manager project beheersing is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	In principe is dezelfde input nodig, namelijk een opdrachtbeschrijving. Echter wordt de opdrachtbeschrijving in aanlegprojecten en dus in de procesbeschrijving vorm gegeven door een scopeformulier en in onderhoudsprojecten wordt de opdrachtbeschrijving vorm gegeven in een project opdracht formulier (POF). In principe is dit dus hetzelfde maar heeft het alleen een andere naam, dit zorgt echter wel voor verwarring binnen onderhoudsprojecten wanneer zij de procesbeschrijving raadplegen.
Q4	Wij wijken hier af van de output zoals wenselijk is in de procesbeschrijving. Wij maken geen PBS omdat dit voor ons nog simpelweg te veel tijd kost. Wel worden werkpakketten beschrijvingen en een WBS gemaakt.
Q5	De activiteiten die betrekking hebben op het opstellen van een PBS zijn als enige niet uitgevoerd, de overige activiteiten wel.
Aanvullende opmerkingen	-

Hoofdproces **Processtap**	Structureren project P3: Structureren organisatie
Q1	Ja, de manager project beheersing is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	Dezelfde input is nodig en ook gebruikt, echter alleen weer opnieuw m.u.v. een PBS.
Q4	De output is nagenoeg gelijk aan de output zoals in aanlegprojecten, namelijk een OBS en een planning van het project.
Q5	De activiteiten worden allemaal op grofweg dezelfde manier uitgevoerd.
Aanvullende opmerkingen	Wat betreft de activiteiten die bij elke processtap beschreven zijn, deze worden nauwelijks geraadpleegd omdat deze activiteiten ondertussen onbewust deel uitmaken van onze dagelijkse werkzaamheden. Ook zijn de activiteiten redelijk nauwkeurig en gedetailleerd beschreven, wat zorgt voor een groot stuk tekst, dit demotiveert ook om de activiteiten nog een keer snel door te nemen of niets gemist is. Van mening ben ik, maar ook enkele andere binnen het IPM-team, dat deze activiteiten overbodig zijn omdat gerekend kan worden op onze professionaliteit en ervaringen.

Hoofdproces **Processtap**	Structureren project P4: Beheren baselines
Q1	Ja, de manager project beheersing is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	In plaats van de PBS gebruiken wij in dit onderhoudsproject een WBS om de baselines te beheren (omdat zoals al eerder genoemd geen middelen beschikbaar waren om een PBS op te stellen).
Q4	De output is hetzelfde als in onderhoudsprojecten; de baselines, het beheren hiervan en de weergave hiervan in de planning.
Q5	De activiteiten komen overeen met de activiteiten die nodig zijn in onderhoudsprojecten.
Aanvullende opmerkingen	Tip: de KAd momenten zijn nuttige momenten in onderhoudsprojecten om te gebruiken als baselines.

Hoofdproces **Processtap**	Structureren project P6: Beheren scope en projectplan
Q1	Ja, de manager project beheersing is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	Wederom is in principe dezelfde input nodig, in dit geval is weer sprake van dezelfde producten alleen zijn hiervoor andere termen/begrippen gebruikt. Het scopeformulier (aanleg) staat gelijk aan het POF (onderhoud). Dit geldt ook voor de wijzigingsvoorstellen op het scopeformulier, deze wijzigingsvoorstellen worden in onderhoudsprojecten APP's genoemd (aanvraag productiepanel).
Q4	Hier geldt hetzelfde als in net benoemd bij de input, het verschil zit hier wederom in de terminologie. De output is in plaats van een bijgewerkt scopeformulier een bijgewerkt POF inclusief bijbehorende APP's.
Q5	Grofweg worden dezelfde activiteiten uitgevoerd, wederom zit het verschil in de terminologie die nu nog niet toepasbaar is en overeenkomt met onderhoudsprojecten.
Aanvullende opmerkingen	-

Appendix III: Interview – Environmental manager

Algemene informatie	
Naam	Jeroen Spanjer
Functie	Omgevings manager
Processtappen	K1, K2, K3, K4, K5, K6, K7
Project	GVO WNZ B-wegen POF 2018
Datum	24-10-2017
Plaats	Rotterdam

Hoofdproces **Processtap**	Analyseren en vaststellen klanteisen K1: Analyseren problemen en projectdoelstellingen
Q1	Gedeeltelijk, de omgevingsmanager heeft hierbij een grote ondersteuning nodig van de rest van het IPM-team.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input is in principe hetzelfde, echter komt dit door de terminologie die gebruikt is wat het verwarrend maakt en niet geheel van toepassing op onderhoudsprojecten is. Het scopeformulier is in ons geval het POF. Ook is een belangrijke brondocumentatie in dit type onderhoudsprojecten de maatregelenlijst.
Q4	De output is nagenoeg gelijk, echter zou nog een belangrijke output toegevoegd kunnen worden in het algemeen, dit is een gecheckt POF (of in aanlegprojecten een gecheckt scopeformulier). Een kleine afwijking is dat het system of interest niet wordt beschreven maar geografisch wordt weergegeven.
Q5	De activiteiten zijn duidelijk en kunnen ook worden uitgevoerd in onderhoudsprojecten. Zoals al aangegeven, de activiteiten worden niet alleen door de omgevingsmanager uitgevoerd maar teambreed opgepakt, daardoor wordt deze processtap altijd snel doorlopen.
Aanvullende opmerkingen	-

Hoofdproces **Processtap**	Analyseren en vaststellen klanteisen K2: Analyseren stakeholders
Q1	Ja, de omgevingsmanager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	Een belangrijke toevoeging aan de benodigde input voor deze processtap is het (veel al aanwezige) verzamelde overzicht van stakeholders van voorgaande jaren en het overzicht van werkvakken (schakels met stakeholders). Dit overzicht is van zowel interne (MH, AM, transitiemanagement) als externe stakeholders (de externe stakeholders zijn geborgd door de interne stakeholder; MH, het Minder Hinder team bepaald de SLOT's met de externe stakeholders).
Q4	De output is hetzelfde.
Q5	Enkele activiteiten worden niet uitgevoerd, dit komt omdat in onderhoudsprojecten nu onderscheid word gemaakt tussen interne en externe stakeholders. Door de eigenschappen van onderhoudsprojecten (op een al bestaand areaal, relatief kleine scope en weinig hinder etc.) zijn minder externe stakeholders bij het proces betrokken. De externe stakeholders die wel van belang zijn worden door interne stakeholders vertegenwoordigd. Voor de externe stakeholders worden dus het belang, de aard, de invloedssfeer en het machtsmiddel niet bepaald en vastgelegd. De overige activiteiten worden wel uitgevoerd; voor interne stakeholders.
Aanvullende opmerkingen	Het onderscheid tussen interne en externe stakeholders wordt in onderhoudsprojecten gemaakt en is erg van belang.

Hoofdproces **Processtap**	Analyseren en vaststellen klanteisen K3: Inventariseren klanteisen
Q1	Ja, de omgevingsmanager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input is nagenoeg gelijk, echter bestaat het stakeholderoverzicht alleen uit interne stakeholders (de externe stakeholders zijn al ingebakend in de interne stakeholders). De twee belangrijkste interne stakeholders (klanten) in onderhoudsprojecten zijn (1) het district (AM) (eisen weergegeven in het POF) en (2) het Minder Hinder team (MH) (eisen weergegeven in het verkeerskader incl. SLOT's).
Q4	De output is hetzelfde.
Q5	De meeste activiteiten worden wel uitgevoerd, echter wel alleen voor interne stakeholders en niet voor externe stakeholders. Het maken van afspraken met de klant over de wijze van aantonen (welke momenten, detailniveaus, bewijsvoering methode, beoordelaar etc.) van de klanteisen wordt eigenlijk niet of in mindere mate uitgevoerd.
Aanvullende opmerkingen	De complexiteit en hoeveelheid van eisen verschilt erg tussen aanleg en onderhoudsprojecten, dit is in onderhoudsprojecten veel minder.

Hoofdproces **Processtap**	Analyseren en vaststellen klanteisen K4: Honoreren klanteisen
Q1	Ja, de omgevingsmanager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	Dezelfde input is benodigd en wordt gebruikt.
Q4	De output is hetzelfde.
Q5	Globaal worden alle activiteiten ook in onderhoudsprojecten uitgevoerd. Een extra toevoeging is dat ook een onderbouwing/besliskader wordt toegevoegd aan de eisen die niet gehonoreerd zijn. Het honoreringsadvies door het IPM-team laten accorderen wordt niet uitgevoerd, dit is een overbodige activiteit door de directe betrokkenheid van alle rolhouders van het IPM-team. Net als in voorgaande processtap is niet gesproken met de klant over de validatiemethoden etc., deze activiteit kan dus niet naar behoren worden uitgevoerd.
Aanvullende opmerkingen	De onduidelijkheid m.b.t. de wijze van het aantonen van klanteisen (moment, bewijsvoering methode, V&V etc.) komt o.a. doordat de termen V&V onduidelijk zijn (niet alleen voor ons maar ook voor de klant).
Aanvullende opmerkingen	Indien namelijk hierover wel naar de klant wordt gevraagd (AM of MH) dan wordt vaak het antwoord gegeven; 'geen idee, dat vertrouw ik aan jullie over want jullie zijn daar ervaren in'.

Hoofdproces **Processtap**	Analyseren en vaststellen klanteisen K5: Samenstellen klanteisenspecificatie
Q1	Ja, de omgevingsmanager is hoofdverantwoordelijke voor deze processtap.
Q2	Gedeeltelijk, een extra toevoeging zou het doel specifieker maken en verbeteren. Het doel eindigt nu bij het honoreren van klanteisen, terwijl het einddoel moet zijn dat deze gehonoreerde klanteisen ook worden opgenomen in de klanteisenspecificatie.
Q3	De input is hetzelfde.
Q4	De output is hetzelfde.
Q5	De activiteiten zijn ook hetzelfde.
Aanvullende opmerkingen	Extra toevoeging; de klanteisenspecificatie wordt gegenereerd m.b.v. GRIP.

Hoofdproces **Processtap**	Analyseren en vaststellen klanteisen K6: Controleren kwaliteit klanteisenspecificatie
Q1	Ja, de omgevingsmanager is hoofdverantwoordelijke voor deze processtap.
Q2	Dit doel wordt als overbodig bevonden, de kwaliteitsborging van de klanteisenspecificatie wordt al geborgd in de voorgaande en laatste processtappen, ofwel in het gehele proces (want ook bijvoorbeeld opnieuw met het V&V).
Q3	Niet specifiek uitgevoerd.
Q4	Niet specifiek uitgevoerd.
Q5	In enkele gevallen worden alleen wat enkele/meest belangrijke klanteisen gecontroleerd of de nieuw opgestelde contracteisen de gekoppelde klanteisen correct afdekken.
Aanvullende opmerkingen	Deze processtap wordt niet uitgevoerd vanwege twee redenen; (1) het wordt als overbodig bevonden omdat de kwaliteit van de klanteisenspecificatie al geborgd wordt in het gehele proces en (2) omdat de klant geen tijd en zin heeft om de kwaliteit van de klanteisenspecificatie te controleren.

Hoofdproces **Processtap**	Analyseren en vaststellen klanteisen K7: Beheren klanteisenspecificatie
Q1	Nee, de omgevingsmanager is hoofdverantwoordelijke gemaakt voor deze processtap (in plaats van de technisch manager) omdat het gehele klanteisen proces al door de omgevingsmanager wordt uitgevoerd en beheerd.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	Dezelfde input wordt gebruikt, inclusief natuurlijk de nieuwe of gewijzigde klanteisen als input.
Q4	De output is hetzelfde.
Q5	Dezelfde activiteiten worden uitgevoerd, echter is het doel van deze processtap niet alleen geborgd in deze processtap maar hangt het ook samen met K4 en K5.
Aanvullende opmerkingen	Extra toevoeging; de klanteisenspecificatie wordt beheerd m.b.v. GRIP.

Appendix IV: Interview – Technical manager

Algemene informatie	
Naam	Lidwien van der Noll
Functie	Technisch manager
Processtappen	P5, S1, S2, S3, S4, S5, S6, S7, S8, S9
Project	GVO WNZ B-wegen POF 2018
Datum	24-10-2017
Plaats	Rotterdam

Hoofdproces **Processtap**	Structureren project P5: V&V-paragraaf bij projectplan
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten. Enkele toevoeging: het doel levert ook een bijdrage aan het kwaliteitsmanagement van het project.
Q3	De input is hetzelfde.
Q4	De output is hetzelfde, maar de kwaliteit hiervan is onvoldoende.
Q5	De activiteiten zijn niet naar behoren uitgevoerd
Aanvullende opmerkingen	De output is in principe hetzelfde, maar qua inhoud voldoet dit echter niet aan de gestelde eisen en dekt het niet het doel van deze processtap. Dit komt omdat onbekend is wat V&V nou eigenlijk inhoud en wat wordt verwacht van een V&V-paragraaf, de inhoud en vormgeving hiervan zijn onbekend.

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S1: Inventariseren en vastleggen nul situatie
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten. Echter is het doel weer toegespitst op aanlegprojecten, in onderhoudsprojecten zou de nul situatie de huidige situatie worden genoemd.
Q3	De input is in principe hetzelfde, echter ook hier zijn de termen toegespitst op het aanlegproces. In plaats van het scopeformulier gebruiken wij het POF.
Q4	De output is nagenoeg gelijk. De beschrijving aanvangssituatie wordt in onderhoudsprojecten vastleggen van de huidige situatie genoemd (dit wordt vormgegeven a.d.h.v. schadeboekjes). De beschikbare areaalgegevens worden in onderhoudsprojecten vormgegeven a.d.h.v. verhardingsonderzoeken, opvragen van tekeningen, omissielijst etc.
Q5	De activiteiten zijn nagenoeg gelijk, echter zijn de activiteiten gericht op een nul situatie bij aanlegprojecten en moeten ze in dit geval iets worden aangepast voor een al bestaande huidige situatie voor onderhoudsprojecten (denk hierbij aan de richtlijn areaalinformatie GWW-projecten, inspectierapporten, omissielijst, veldwerk, schadeboekjes etc.)
Aanvullende opmerkingen	Hier ligt een groot risico in onderhoudsprojecten (in tegenstelling tot aanlegprojecten), de areaalgegevens zijn vaak verouderd of incompleet en dus niet actueel.

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S2: Gebruiken basisspecificatie normen en richtlijnen
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input zijn hier inderdaad de basisspecificaties, normen en richtlijnen (denk hierbij aan IVOD-contracten en E&C modelcontracten). Onduidelijk is hoe de systeemdecompositie voor dit doel als input gebruikt kan/moet worden.
Q4	In principe dezelfde output, alleen wordt deze output benoemd als systeemspecificatie versie 1.
Q5	De activiteiten worden allemaal op grofweg dezelfde manier uitgevoerd.
Aanvullende opmerkingen	Onduidelijk is wat het precieze verschil is tussen de systeemspecificatie en de contractspecificatie, de toegevoegde waarde van een systeemspecificatie is onduidelijk want de systeemspecificatie wordt nu gezien als gelijk ook de uiteindelijke contractspecificatie.

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S3: Analyseren
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt gedeeltelijk overeen met het doel dat gesteld wordt in onderhoudsprojecten (het analyseren van aspecten en raakvlakken is overbodig bevonden omdat deze er amper zijn en wordt niet uitgevoerd in onderhoudsprojecten).
Q3	De input is hetzelfde.
Q4	De functie-analyse is dezelfde output (deze wordt in onderhoudsprojecten uitgevoerd o.b.v. de maatregelenlijst). De raakvlakanalyse, contextdiagram en aspectenanalyse worden niet uitgevoerd omdat deze (raakvlakken en aspecten) er simpelweg niet echt zijn in onderhoudsprojecten (het gaat namelijk niet om het hele systeem maar om alleen kleine stukken die vervangen moeten worden). Versie 2 van de systeemspecificatie is hier ook output.
Q5	De activiteiten m.b.t. de functie-analyse worden uitgevoerd, de overige activiteiten m.b.t. o.a. raakvlak- en aspectenanalyse worden niet uitgevoerd omdat dit in onderhoudsprojecten niet nodig en van toepassing is.
Aanvullende opmerkingen	-

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S4: Structureren en alloceren
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt gedeeltelijk overeen met het doel dat gesteld wordt in onderhoudsprojecten (het structureren van aspecten en raakvlakken is overbodig bevonden omdat deze er amper zijn en wordt dus niet uitgevoerd in onderhoudsprojecten).
Q3	De input wordt niet hetzelfde benoemd maar is wel hetzelfde (wij noemen het al 'systeemspecificatie (versie 2)' terwijl in de procesbeschrijving alle onderdelen die in de systeemspecificatie staan apart worden benoemd.
Q4	De output komt niet geheel overeen met elkaar, de functie-object allocatie matrix en contexttabel worden niet gemaakt (wel de functieboom en objectenboom, dit wordt als voldoende ervaren omdat de onderhoudsprojecten over het algemeen niet heel groot en complex zijn en weinig raakvlakken hebben). Versie 3 van de systeemspecificatie is hier ook output.
Q5	Hetzelfde geldt voor de activiteiten, de activiteiten m.b.t. de matrix en contexttabel worden niet uitgevoerd omdat de systemen en objecten niet complex zijn en er weinig raakvlakken zijn.
Aanvullende opmerkingen	-

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S5: Ontwerpen
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Deze processtap wordt niet uitgevoerd. Het doel wordt dus als niet van toepassing beschouwen in onderhoudsprojecten.
Q3	-
Q4	-
Q5	Deze activiteiten worden niet uitgevoerd omdat naar onze mening geen ontwerp wordt gemaakt omdat in onderhoudsprojecten het ontwerp al bestaat.
Aanvullende opmerkingen	Dit is een belangrijk verschil tussen aanleg en onderhoudsprojecten. Wij ontwerpen niet en voeren deze processtap daarom ook niet uit.

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S6: Samenstellen systeemspecificatie
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input wordt niet hetzelfde benoemd maar is wel hetzelfde (wij noemen het al 'systeemspecificatie (versie 3)' terwijl in de procesbeschrijving alle onderdelen die in de systeemspecificatie staan apart worden benoemd.
Q4	De output is hetzelfde (definitieve systeemspecificatie)
Q5	De activiteiten worden allemaal op grofweg dezelfde manier uitgevoerd.
Aanvullende opmerkingen	-

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S7: Controleren kwaliteit systeemspecificatie
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Dit doel wordt als overbodig bevonden, de kwaliteitsborging van de systeemspecificatie wordt al geborgd in de voorgaande en laatste processtappen, ofwel in het gehele proces (want ook bijvoorbeeld opnieuw met het V&V).
Q3	Niet specifiek uitgevoerd.
Q4	Niet specifiek uitgevoerd.
Q5	De activiteiten worden over het algemeen niet uitgevoerd, het sjabloon systeemspecificatie is bijvoorbeeld niet geraadpleegd. In enkele gevallen worden alleen kennisdelingssessies binnen het IPM-team en andere B-wegen teams ondernomen.
Aanvullende opmerkingen	-

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S8: Verifiëren en valideren van het systeem
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel van deze processtap is onduidelijk en onbekend is hoe hier precies invulling aan moet worden gegeven.
Q3	-
Q4	-
Q5	De activiteiten worden niet (of niet naar behoren) uitgevoerd omdat onbekend is hoe hier precies invulling aan moet worden gegeven.
Aanvullende opmerkingen	Evenals in het begin (P5; het opstellen van een V&V paragraaf), is het onbekend wat nou precies V&V inhoudt en hoe hier invulling aan moet worden gegeven in onderhoudsprojecten.

Hoofdproces **Processtap**	Ontwerpen en specificeren van het systeem S9: Beheren systeemspecificatie
Q1	Ja, de technisch manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input is hetzelfde.
Q4	De output is hetzelfde (definitieve systeemspecificatie).
Q5	Dezelfde activiteiten worden uitgevoerd, echter is het doel van deze processtap niet alleen geborgd in deze processtap maar hangt het ook samen met alle voorgaande processtappen.
Aanvullende opmerkingen	Extra toevoeging; de systeemspecificatie word gegenereerd en beheerd m.b.v. GRIP.

Appendix V: Interview – Contract manager

Algemene informatie	
Naam	Reita Biere
Functie	Contract manager
Processtappen	C1, C2, C3, C4
Project	GVO WNZ B-wegen POF 2018
Datum	2-11-2017
Plaats	Rotterdam

Hoofdproces **Processtap**	Uitwerken contractspecificatie C1: Bepalen oplossingsruimte contractspecificatie
Q1	Gedeeltelijk, de contract manager heeft hierbij een grote ondersteuning nodig van de technisch manager.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input is hetzelfde.
Q4	De output komt niet overeen, de output van deze processtap is de VSE en de VSP (ofwel de contractspecificatie). Hierin is niet de oplossingsruimte of ontwerpvrijheid etc. specifiek beschreven of benadrukt.
Q5	Al deze activiteiten zijn naar mijn mening al in eerdere processtappen uitgevoerd (voornamelijk door de technisch manager).
Aanvullende opmerkingen	Het is onduidelijk wat het precieze verschil is tussen de systeemspecificatie en contractspecificatie, het is onduidelijk wat de definitie en het doel is per specificatie. Onbekend wat de toegevoegde waarde is van een systeemspecificatie en contractspecificatie. Ook is het onduidelijk wat hier wordt bedoeld met de contractspecificatie; is dit alleen de Vraag Specificatie Eisen (VSE) of hoort de Vraag Specificatie Proces (VSP) hier ook bij.

Hoofdproces **Processtap**	Uitwerken contractspecificatie C2: Bepalen scope contractspecificatie
Q1	Gedeeltelijk, de contract manager (verantwoordelijk voor VSP) heeft hierbij een grote ondersteuning nodig van de technisch manager (verantwoordelijk voor VSE).
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input is komt gedeeltelijk overeen, naast de inkoopstrategie en risicodossier worden ook het POF en ARW als input gebruikt.
Q4	De output komt niet overeen, de output is in dit geval het inkoopplan, contractstukken en aanbestedingsstukken.
Q5	Nagenoeg worden dezelfde activiteiten uitgevoerd, echter soms wel bepaald o.b.v. andere specifieke project bestanden (denk aan de maatregelenlijst etc.).
Aanvullende opmerkingen	-

Hoofdproces **Processtap**	Uitwerken contractspecificatie C3: Samenstellen contractspecificatie
Q1	Ja, de contract manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input wijkt af van de input zoals aangegeven in de procesbeschrijving. De klanteisenspecificatie wordt gebruikt (in plaats van de systeemspecificatie), ook worden de modellen voor aanbestedingsdossiers en inschrijf en beoordeling documenten gebruikt.
Q4	De output is niet hetzelfde, dit wordt veroorzaakt door de verschillende type contractvormen (aanleg: D&C en DBFM, onderhoud: E&C en prestatiecontract). De output voor E&C is VSE en VSP. De output voor prestatiecontracten is een algemene VS. De uiteindelijke output zijn dus de contractstukken en aanbestedingsdocumenten (bv. inkoopplan etc.).
Q5	De activiteiten worden niet geheel naar behoren uitgevoerd, gebruik wordt gemaakt van het sjabloon voor VSE en VSP (voor D&C en DBFM contracten), terwijl deze contracten niet van toepassing zijn in onderhoudsprojecten.
Aanvullende opmerkingen	Onbekend wat precies het verschil is tussen de klanteisenspecificatie, systeemspecificatie en contractspecificatie en wanneer welke specificatie gebruikt moet worden. De verschillende contractvormen binnen aanleg- en onderhoudsprojecten zorgen hier voor verwarring en benodigde aanpassingen.

Hoofdproces **Processtap**	Uitwerken contractspecificatie C4: Controleren kwaliteit contractspecificatie
Q1	Ja, de contract manager is hoofdverantwoordelijke voor deze processtap.
Q2	Het doel komt overeen met het doel dat gesteld wordt in onderhoudsprojecten.
Q3	De input is nagenoeg gelijk, contract stukken en aanbestedingsdocumenten. Echter is hier voor specifiek E&C contract invulling aan gegeven; VSE en VSP.
Q4	De output is hetzelfde.
Q5	Nagenoeg dezelfde activiteiten worden uitgevoerd, echter is het doel van deze processtap niet alleen geborgd in deze processtap maar hangt het ook samen met alle voorgaande processtappen. Ook worden extra activiteiten uitgevoerd zoals een interne kwaliteitsborgings-, integraliteits- en KAd-toetsen.
Aanvullende opmerkingen	In tegenstelling tot de andere 'controle' processtappen (K6 en S7) wordt deze controle als van groot belang en van toegevoegde waarde ervaren in dit proces. De gehele procesbeschrijving hangt zo samen, het wordt meer gezien als een spinnenweb in plaats van 'stappenplan', de vorm van dit product kan wellicht beter op een andere manier vormgegeven worden zodat de samenhang beter zichtbaar wordt (wellicht meer dat de kleuren die nu gebruikt worden ook overlopen en verschillen per processtap).

Appendix VI: Process model

1. Structureren project

<table>
<tr><th colspan="2">Structureren project
P1 Analyseren projectopdracht</th></tr>
<tr><td>IPM-rol</td><td>Project manager (PM)</td></tr>
<tr><td>Doel</td><td>Toevoeging:
Belangrijk is om inzicht te verkrijgen in de maakbaarheid en haalbaarheid van de opdracht zoals gedefinieerd in het project opdracht formulier (POF).</td></tr>
<tr><td>Input</td><td>Verduidelijking:
- Projectopdracht = de projectopdracht staat in aanlegprojecten in de opdrachtbrief met het scopeformulier en in onderhoudsprojecten in het POF.
- (Bron)documentatie van het project = denk bij onderhoudsprojecten aan bijvoorbeeld de RUPS maatregelenlijst.</td></tr>
<tr><td>Activiteiten</td><td>Toevoeging:
De activiteiten die uitgevoerd moeten worden, zijn in de huidige procesbeschrijving gebaseerd op de structuur en inhoud van het scopeformulier, echter moeten de activiteiten voor onderhoudsprojecten worden gebaseerd op de structuur en inhoud van het POF. De volgende activiteiten dienen uitgevoerd te worden:
- Het analyseren van de POF (huidige situatie, doelstelling, afbakening etc.) en de brondocumentatie van het project (denk hierbij bijvoorbeeld aan de RUPS maatregelenlijst etc.).
- Het analyseren van het budget, de planning, omgevingsmanagement, publieksgericht netwerk management, risico's, informatie overdracht, proces afspraken en overige gegevens t.b.v. het uitvoeren van de opdracht.

Verduidelijking:
Deze processtap heeft samen met processtap P6 (beheren scope) grote invloed op processtap S5 (ontwerpen). Belangrijk in deze processtap is dan ook om m.b.v. het POF (incl. RUPS maatregelenlijst) de scope zo gedetailleerd en goed mogelijk te onderzoeken, uit te werken en af te bakenen. Vaak is namelijk nog niet bekend tot in hoeverre een schade bijvoorbeeld enkel visueel (laag detailniveau) of zelfs constructief (hoog detailniveau) is. Het is dus van groot belang dat het IPM-team hier bewust van is en verder onderzoek naar doet omdat dit grote invloed heeft op het latere ontwerpproces (S5) en het detailniveau waarop gespecificeerd moet worden.</td></tr>
<tr><td>Output</td><td>Verduidelijking:
- Scopeformulier = (ondertekend) POF</td></tr>
</table>

Structureren project P2 Structureren werkpakketten en producten	
IPM-rol	Manager project beheersing (MPB)
Doel	✓ (de '✓' staat voor geen toevoegingen/verduidelijkingen etc. op hoe het in de huidige procesbeschrijving beschreven staat)
Input	*Verduidelijking:* - Scopeformulier = POF → dit is de opdrachtbeschrijving van het project, in aanlegprojecten staat dit in het scopeformulier, in onderhoudsprojecten in het POF.
Activiteiten	✓
Output	*Verduidelijking:* De output, zoals in de huidige procesbeschrijving beschreven, is ook wenselijk voor onderhoudsprojecten. Het opstellen van een PBS en werkpakket beschrijvingen kost in het begin tijd, maar is het investeren waard voor het repeterende karakter van alle volgende onderhoudsprojecten in de productielijn B.

Structureren project P3 Structureren organisatie	
IPM-rol	MPB
Doel	✓
Input	✓
Activiteiten	*Toevoeging*: Maak een verbinding tussen de opgestelde OBS en de werkpakketten met bijbehorende producten, hierdoor ontstaat een onderverdeling hiervan over de verschillende IPM-rolhouders.
Output	✓

Structureren project P4 Beheren baselines	
IPM-rol	MPB
Doel	✓
Input	*Toevoeging*: Indien geen PBS aanwezig is, kan de WBS eventueel gebruikt worden om de baselines te beheren. *Toevoeging*: De geplande KAd momenten kunnen ook als input dienen om baselines te plannen en te beheren.
Activiteiten	✓
Output	✓

Structureren project P5 V&V-paragraaf bij projectplan	
IPM-rol	Technisch manager (TM)
Doel	*Toevoeging*: ‘Project specifiek vastleggen van taken en verantwoordelijkheden m.b.t. V&V bij systeemontwikkeling binnen het IPM-team’ + ‘en een bijdrage leveren aan de kwaliteitsborging van het project’.
Input	✓ (de ‘✓’ staat voor geen toevoegingen/verduidelijkingen etc. op hoe het in de huidige procesbeschrijving beschreven staat)
Activiteiten	*Verduidelijking:* Denk bij het onderverdelen van de V&V activiteiten aan de verdeling tussen de opdrachtgever (OG) en opdrachtnemer (ON). Voorbeelden van onder te verdelen V&V activiteiten: - OG: in dit geval het IPM-team, is verantwoordelijk voor de V&V activiteiten m.b.t. enkele kleine ontwerpkeuzes die worden gemaakt (denk hierbij aan een ontwerpkeuze m.b.t. een nieuwe soort deklaag, de stroefheid hiervan moet bijvoorbeeld geverifieerd en gevalideerd worden) en de opgestelde SLOT’s moeten op hun beurt t.z.t. ook geverifieerd en gevalideerd worden aan de opgestelde klant- en systeemeisen. - ON: verantwoordelijk voor de V&V activiteiten m.b.t. overige gemaakte ontwerpkeuzes en het daadwerkelijk gerealiseerde werk. *Verduidelijking:* - Belangrijk is dat per eis V&V-voorwaarden worden vastgesteld, denk hierbij aan: bewijsvoeringsmethode (verificatie- en/of validatiemethode), (SMART) criteria, beoordelaar(s), fasering (tijdstip waarop op V&V moet plaats vinden) etc. (zie WWB-0044 Verifiëren en valideren bij systeemontwikkeling). - Dit is van groot belang en heeft invloed op het naar behoren uit kunnen voeren van de processtap K3 (inventariseren klanteisen) en uiteindelijk op processtap S8 (verifiëren en valideren van het systeem).
Output	*Verduidelijking:* De output zoals beschreven in de huidige procesbeschrijving is ook de gewenste output voor onderhoudsprojecten, echter kan deze output erg verschillen (qua invulling, gedetailleerdheid etc.) waardoor een template voor de gewenste output is gemaakt (WWB-0044 Verifiëren en valideren bij systeemontwikkeling). Tip: gebruik het sjabloon V&V plan in bijlage A.

<table>
<tr><th colspan="2">Structureren project
P6 Beheren scope en projectplan</th></tr>
<tr><td>IPM-rol</td><td>MPB</td></tr>
<tr><td>Doel</td><td>✓</td></tr>
<tr><td>Input</td><td>Verduidelijking:
- Scopeformulier = POF → dit is de opdrachtbeschrijving van het project, in aanlegprojecten heet dit het scopeformulier, in onderhoudsprojecten het POF.
- Wijzigingsvoorstellen op scopeformulier (VTW) = Aanvraag Productie Panel (APP) → de zogenoemde wijzigingsvoorstellen in aanlegprojecten worden in onderhoudsprojecten APP’s genoemd.</td></tr>
<tr><td>Activiteiten</td><td>Verduidelijking:
De activiteiten, zoals in de huidige procesbeschrijving beschreven, zijn hetzelfde in onderhoudsprojecten, echter zit hier alleen een klein verschil in de gebruikte terminologie zoals hierboven bij de input al is benoemd. Deze onderhoudstermen moeten worden doorgevoerd in deze gehele processtap.

Verduidelijking:
Deze processtap heeft samen met processtap P1 (analyseren projectopdracht) grote invloed op processtap S5 (ontwerpen). Belangrijk in deze processtap is dan ook om m.b.v. het POF (incl. RUPS maatregelenlijst) de scope zo gedetailleerd en goed mogelijk te onder zoeken, uit te werken en af te bakenen omdat vaak nog niet bekend is tot in hoeverre een schade bijvoorbeeld enkel visueel (laag detailniveau) of zelfs constructief (hoog detailniveau) is. Het is dus van groot belang dat het IPM-team hier bewust van is en verder onderzoek naar doet omdat dit grote invloed heeft op het latere ontwerpproces (S5) en het detailniveau hiervan.</td></tr>
<tr><td>Output</td><td>Verduidelijking:
- Bijgewerkt scopeformulier (incl. VTW’s) = bijgewerkt POF (incl. APP’s)</td></tr>
</table>

2. Analyseren en vaststellen klanteisen

Analyseren en vaststellen klanteisen **K1 Analyseren problemen en projectdoelstellingen**	
IPM-rol	*Verduidelijking*: De verantwoordelijke IPM-rolhouder van deze processtap is de omgevingsmanager (OM), echter is expliciet in deze processtap een grote ondersteuning nodig van de rest van het IPM-team.
Doel	✓ (de '✓' staat voor geen toevoegingen/verduidelijkingen etc. op hoe het in de huidige procesbeschrijving beschreven staat)
Input	*Verduidelijking*: - Scopeformulier = POF → dit is de opdrachtbeschrijving van het project, in aanlegprojecten heet dit het scopeformulier, in onderhoudsprojecten het POF. - Denk bij de brondocumentatie van het project in onderhoudsprojecten aan bijvoorbeeld de RUPS maatregelenlijst etc.
Activiteiten	✓
Output	*Verduidelijking*: Het system of interest kan zowel tekstueel als geografisch worden weergegeven *Toevoeging*: - Gecheckt POF

Analyseren en vaststellen klanteisen **K2 Analyseren stakeholders**	
IPM-rol	OM
Doel	✓
Input	*Verduidelijking*: - Scopeformulier = POF - Brondocumentatie van het project waaronder de stakeholdersanalyse = het (veelal aanwezige) verzamelde overzicht van interne en externe stakeholders van voorgaande jaren/projecten en het overzicht van werkvakken
Activiteiten	*Niet van toepassing*: In de activiteiten, zoals in de huidige procesbeschrijving beschreven, moet voor elke stakeholder ook zijn belang en de aard van het belang, de invloedssfeer en het machtsmiddel worden vastgelegd. Echter, wordt in onderhoudsprojecten duidelijk onderscheid worden gemaakt tussen interne en externe stakeholders. Door de eigenschappen van onderhoudsprojecten (denk hierbij bijvoorbeeld aan een al bestaand areaal, relatief kleine scope en weinig hinder etc.) zijn over het algemeen weinig externe stakeholders bij onderhoudsprojecten betrokken. Dit kleine aantal externe stakeholders (denk hierbij bijvoorbeeld aan wegbeheerders en hulpdiensten) worden veelal geborgd en vertegenwoordigd door interne stakeholders (denk hierbij bijvoorbeeld aan het Minder Hinder team), hierdoor hoeven de activiteiten van deze processtap vaak enkel worden uitgevoerd voor interne stakeholders en zelden voor externe stakeholders.
Output	✓

Analyseren en vaststellen klanteisen K3 Inventariseren klanteisen	
IPM-rol	OM
Doel	✓
Input	*Verduidelijking*: - Stakeholdersoverzicht = stakeholdersoverzicht van veelal enkel interne stakeholders - Gespreknotities en verslagen met van overleggen met stakeholders (denk hierbij bijvoorbeeld aan het verkeerskader van het Minder Hinder team en een overzicht van de eisen van het district)
Activiteiten	*Niet van toepassing*: Met het uitvoeren van de activiteiten, zoals in de huidige procesbeschrijving beschreven, moet in het achterhoofd gehouden worden dat de aard, hoeveelheid en complexiteit van de stakeholderseisen erg verschilt tussen aanleg- en onderhoudsprojecten (in onderhoudsprojecten alles in mindere mate, hier is voornamelijk sprake van twee belangrijke interne stakeholders namelijk het district (eisen in POF) en het Minder Hinder team (eisen in verkeerskader incl. SLOT’s)). De activiteiten zijn dus vaak alleen van toepassing op interne stakeholders (en zelden op externe stakeholders, deze zijn veelal geborgd en vertegenwoordigd door interne stakeholders). *Verduidelijking*: Belangrijk is, met het oogpunt vanuit processtappen P5 (maken V&V paragraaf bij projectplan) en S8 (verifiëren en valideren van het systeem), dat de activiteiten m.b.t. het afspraken maken over V&V-activiteiten met de stakeholders wel degelijk worden uitgevoerd (denk hierbij aan het maken van afspraken over wanneer de klant tevreden is, bewijsvoeringsmethode, criteria, beoordelaars, fase etc.), voornamelijk met de twee belangrijkste interne stakeholders namelijk het district en het Minder Hinder team.
Output	✓

Analyseren en vaststellen klanteisen K4 Honoreren klanteisen	
IPM-rol	*Verduidelijking*: De verantwoordelijke IPM-rolhouder van deze processtap is de OM, echter is expliciet in deze processtap een grote ondersteuning nodig van de rest van het IPM-team (voornamelijk de TM en CM).
Doel	✓
Input	✓
Activiteiten	*Niet van toepassing*: Het honoreringsadvies kan in de meeste gevallen direct door het gehele IPM-team geaccordeerd worden door de directe betrokkenheid van alle IPM-rolhouders gedurende dit proces.
Output	*Toevoeging*: - Besliskader - Onderbouwing van de niet gehonoreerde klanteisen - Verwijzing per klanteis naar de uiteindelijke contracteis (VSE of VSP) - Mandaatadvies van ICG

Analyseren en vaststellen klanteisen K5 Samenstellen klanteisenspecificatie	
IPM-rol	OM
Doel	*Toevoeging*: 'Het gestructureerd documenteren van alle stakeholders met bijbehorende klanteisen en inzichtelijk maken welk deel van de klanteisen is gehonoreerd' + 'en deze gehonoreerde klanteisen opnemen in de klanteisenspecificatie'.
Input	*Verduidelijking*: - Scopeformulier = POF - Stakeholdersoverzicht = stakeholdersoverzicht van veelal enkel interne stakeholders
Activiteiten	✓
Output	✓

Analyseren en vaststellen klanteisen K6 Controleren kwaliteit klanteisenspecificatie	
IPM-rol	OM
Doel	✓
Input	*Verduidelijking*: - Scopeformulier = POF
Activiteiten	*Verduidelijking*: Wanneer deze activiteiten als overbodig of tijdrovend worden bevonden (door zowel het IPM-team als de stakeholders) is het mogelijk om de activiteiten uit te voeren op enkele en de meest belangrijkste klanteisen. De voornaamste bedoeling van deze processtap is een expliciete kwaliteitscontrole.
Output	✓

Analyseren en vaststellen klanteisen K7 Beheren klanteisenspecificatie	
IPM-rol	*Toevoeging*: De verantwoordelijke IPM-rolhouder voor deze processtap, zoals in de huidige procesbeschrijving beschreven, is de technisch manager (TM). Het is ook mogelijk dat deze processtap door de OM uitgevoerd wordt omdat het gehele proces van het analyseren en vaststellen van de klanteisen al door de OM wordt uitgevoerd en beheerd.
Doel	✓
Input	✓
Activiteiten	✓
Output	*Verduidelijking*: - Wijzigingsvoorstellen op scopeformulier (VTW) = Aanvraag Productie Panel (APP) → de zogenoemde wijzigingsvoorstellen in aanlegprojecten worden in onderhoudsprojecten APP's genoemd.

3. Ontwerpen en specificeren van het systeem

Ontwerpen en specificeren van het systeem **S1 Inventariseren en vastleggen nulsituatie**	
IPM-rol	Technisch manager (TM)
Doel	*Verduidelijking*: ‘Het verkrijgen van inzicht in en vastleggen van de ~~nulsituatie~~ aanvangssituatie’. In tegenstelling tot aanlegproject, bepaalt de aanvangssituatie welk onderhoud nodig is en bepaalt daarmee ook in grote mate de scope van het onderhoudsproject. Dit is een groot verschil tussen aanleg- en onderhoudsprojecten, in onderhoudsprojecten is deze processtap belangrijk en risicovol, de areaalgegevens zijn vaak verouderd of incompleet. Hierdoor moet nog veel onderzocht worden om de definitieve scope te kunnen bepalen.
Input	*Verduidelijking*: - Scopeformulier = POF → dit is de opdrachtbeschrijving van het project, in aanlegprojecten heet dit het scopeformulier, in onderhoudsprojecten het POF. - Denk bij de brondocumentatie van het project in onderhoudsprojecten aan bijvoorbeeld de RUPS maatregelenlijst etc.
Activiteiten	*Toevoeging*: Theoretisch gezien ligt hier een belangrijke taak voor de regisseur asset management (RAM), deze hoort te beschikken over de gegevens van de aanvangssituatie. Echter blijkt uit de praktijk dat dit niet altijd het geval is, daardoor worden deze activiteiten veelal toch door het IPM-team uitgevoerd. Belangrijk is om samen (RAM en IPM-team), in overleg, de aanvangssituatie in beeld te krijgen en afspraken te maken over de verwachtingen en bijbehorende aan te leveren gegevens.
Output	*Verduidelijking*: - Beschrijving aanvangssituatie = het vastleggen van de aanvangssituatie, denk hierbij bijvoorbeeld aan inspectierapporten, veldwerk, schadeboekjes etc. → dit houdt hetzelfde in, echter wordt hiervoor in onderhoudsprojecten vaak andere terminologie gebruikt. - Beschikbare areaalgegevens = lijst van de beschikbare areaalgegevens en omissielijst *Toevoeging*: - Definitieve scopelijst en APP’s

Ontwerpen en specificeren van het systeem **S2 Gebruiken basisspecificaties, normen en richtlijnen**	
IPM-rol	TM
Doel	✓
Input	*Verduidelijking*: - Scopeformulier = POF (incl. RUPS maatregelenlijst)
Activiteiten	✓
Output	✓

<table>
<tr><th colspan="2">Ontwerpen en specificeren van het systeem
S3 Analyseren</th></tr>
<tr><td>IPM-rol</td><td>TM</td></tr>
<tr><td>Doel</td><td>✓</td></tr>
<tr><td>Input</td><td>✓</td></tr>
<tr><td>Activiteiten</td><td>Verduidelijking:
De activiteiten m.b.t. het analyseren van de klanteisen, het formuleren van de systeem eisen en het uitvoeren van een functie-analyse zijn noodzakelijke activiteiten en zeker ook van belang en van toepassing in onderhoudsprojecten. Deze activiteiten zijn niet alleen nodig om uiteindelijk ontwerpkeuzes te kunnen maken en het abstractieniveau van het systeem te definiëren, maar ook om daarmee de contractscope en oplossingsvrijheid voor de opdrachtnemer te bepalen en de klanteisen zo goed en volledig mogelijk te kunnen vertalen naar systeemeisen.

Niet van toepassing:
Een aantal activiteiten, zoals in de huidige procesbeschrijving beschreven zijn (denk hierbij aan het maken van een raakvlakanalyse, contextdiagram, functie- en aspectenanalyse), hoeven echter vrijwel zelden expliciet uitgevoerd te worden omdat deze al beschikbaar zijn van voorgaande projecten en er simpelweg nog maar weinig ontwerpkeuzes gemaakt hoeven worden (door het lage abstractieniveau van onderhoudsprojecten). Echter is een impliciete analyse/check is wel verstandig om tot een volledige set systeemeisen te komen.</td></tr>
<tr><td>Output</td><td>Niet van toepassing:
Slechts in specifieke gevallen (knelpunten, grote risico's, afwijkingen op wat standaard is) moeten deze producten wel expliciet worden opgesteld:
- Functie-analyse rapport
- Raakvlakanalyse en contextdiagram (eventueel raakvlak beheers document)
- Aspectenanalyse (waaronder de RAMS analyse)</td></tr>
</table>

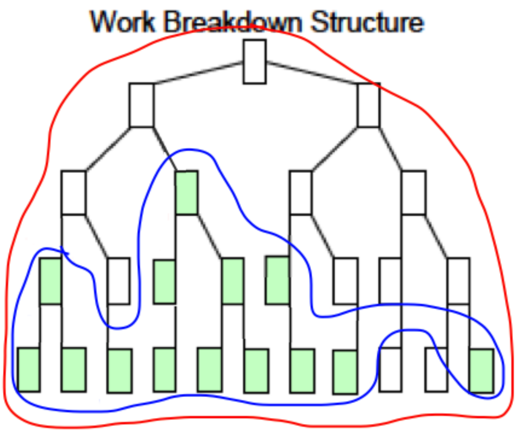
<table>
<tr><th colspan="2">Ontwerpen en specificeren van het systeem
S4 Structureren en alloceren</th></tr>
<tr><td>IPM-rol</td><td>TM</td></tr>
<tr><td>Doel</td><td>✓</td></tr>
<tr><td>Input</td><td>Verduidelijking:
- Beschrijving nulsituatie = beschrijving aanvangssituatie

Niet van toepassing:
Wel indien aanwezig uit de vorige processtap:
- Functie-analyse rapport
- Raakvlakanalyse en contextdiagram (eventueel raakvlak beheers document)
- Aspectenanalyse (waaronder de RAMS analyse)</td></tr>
<tr><td>Activiteiten</td><td>Verduidelijking:
De activiteiten m.b.t. het opstellen van een functieboom (FBS) en object(typ)enboom (SBS) zijn noodzakelijke activiteiten en ook van belang en van toepassing in onderhoudsprojecten.

Niet van toepassing:
De overige activiteiten, zoals in de huidige procesbeschrijving beschreven (denk hierbij aan de functie-object allocatie matrix en contexttabel), zijn optioneel.</td></tr>
<tr><td>Output</td><td>Verduidelijking:
- Systeemdecomposities = FBS en SBS</td></tr>
</table>

Ontwerpen en specificeren van het systeem **S4 Structureren en alloceren**	
	Niet van toepassing: De overige output zoals functie-object allocatie matrix en contexttabel hoeven dus vrijwel zelden/nooit uitgevoerd te worden in onderhoudsprojecten omdat de systemen en objecten in deze projecten niet complex zijn en weinig/geen raakvlakken bevatten, belangrijk is wel dat deze systemen en objecten duidelijk worden beschreven.

Ontwerpen en specificeren van het systeem **S5 Ontwerpen**	
IPM-rol	TM
Doel	✓
Input	*Niet van toepassing*: Wel indien aanwezig uit eerdere processtappen: - Functie-analyse rapport - Raakvlakanalyse en contextdiagram (eventueel raakvlak beheers document) - Aspectenanalyse (waaronder de RAMS analyse)
Activiteiten	*Verduidelijking*: De veronderstelling bestaat dat ontwerpen in onderhoudsprojecten niet aan de orde is omdat het werk al bestaat en enkel naar de originele staat moet worden teruggebracht, veel gegevens liggen dan ook al vast (denk hierbij bijvoorbeeld aan de maatregelen en SLOT's), echter is deze veronderstelling onjuist en worden wel degelijk ontwerpkeuzes gemaakt in onderhoudsprojecten. De voorbeelden van ontwerpen in deze processtap en de bekende ontwerp voorbeelden in het algemeen (denk hierbij aan het bekende voorbeeld: 'het creëren van een oeververbinding van A naar B', dit kan vervuld worden door bijvoorbeeld een ontwerpkeuze te maken voor een brug of juist een tunnel) zijn specifiek toegespitst op aanlegprojecten en ontwerpen op een hoog abstractieniveau. In onderhoudsprojecten is het ontwerpen en het maken van ontwerpkeuzes ook zeker aan de orde, maar grotendeels op een lager abstractieniveau, waardoor ontwerpkeuzes vaak niet worden herkend terwijl deze wel degelijk aanwezig zijn en ook, al dan niet bewust, worden gemaakt. Enkele voorbeelden van ontwerpkeuzes in onderhoudsprojecten: - Een schade is geconstateerd, namelijk 'de verf van een hekwerk bladdert af' en hiervoor is een maatregel voorgesteld, namelijk 'de verf moet worden vervangen', hier wordt al een ontwerpkeuze gemaakt en kunnen nog verdere ontwerpkeuzes worden gemaakt, denk hierbij bijvoorbeeld aan de keuzes van het type conserveringssysteem, materiaalkenmerken zoals chemische samenstelling of kleur e.d. - Nog een schade is geconstateerd, namelijk 'de deklaag is beschadigd' en hiervoor is een maatregel voorgesteld, namelijk 'de deklaag moet worden vervangen', hier moet een ontwerpkeuze worden gemaakt voor een nieuw type deklaag, bijvoorbeeld de keuze tussen het aanbrengen van een ZOAB, DAB of eventueel geluidsstille deklaag. - In het geval van het voorgaande voorbeeld moet een ontwerpkeuze gemaakt worden op een laag abstractieniveau, echter kan dit altijd naar een hoger abstractieniveau worden gebracht. Indien bijvoorbeeld de schade aan de deklaag niet alleen visueel is, maar constructief blijkt te zijn, in dit geval moeten ook opnieuw ontwerpkeuzes worden gemaakt m.b.t. de fundering, ofwel op een hoger abstractieniveau.

Ontwerpen en specificeren van het systeem **S5 Ontwerpen**	
	In onderstaande figuur is grofweg het abstractieniveau van specificeren en ontwerpen weergegeven. Het abstractieniveau in aanlegprojecten (rode kader) begint op het hoogste abstractieniveau, het abstractieniveau wordt daarna steeds lager. In onderhoudsprojecten (blauwe kader) wordt door het abstractieniveau van de systeemelementen die in de projectscope vallen het abstractieniveau van specificeren en ontwerpen bepaald. Dit abstractieniveau is vaak op een lager niveau dan aanlegprojecten. 
Output	✓

Ontwerpen en specificeren van het systeem **S6 Samenstellen systeemspecificatie**	
IPM-rol	TM
Doel	✓
Input	*Niet van toepassing*: De volgende input is optioneel in onderhoudsprojecten: - Contexttabel - Contextdiagram - Functie-object allocatie matrix
Activiteiten	✓
Output	✓

Ontwerpen en specificeren van het systeem **S7 Controleren kwaliteit systeemspecificatie**	
IPM-rol	TM
Doel	✓
Input	*Verduidelijking*: - Scopeformulier = POF
Activiteiten	✓
Output	✓

Ontwerpen en specificeren van het systeem S8 Verifiëren en valideren van het systeem	
IPM-rol	TM
Doel	✓
Input	✓
Activiteiten	*Verduidelijking*: Moeilijkheden die worden ervaren in deze processtap worden echter niet veroorzaakt door deze processtap, maar door de relatie met en invloed van de voorgaande processtappen: P5 (maken V&V paragraaf bij projectplan) en K3 (inventariseren klanteisen), hier worden de meeste moeilijkheden daadwerkelijk ervaren. Indien deze processtappen (P5 en K3) volledig en correct worden uitgevoerd, zijn namelijk de V&V activiteiten voor het IPM-team al beschreven en onderverdeeld en zijn deze op hun beurt ook in overleg met de stakeholders naar ook hun tevredenheid verder uitgewerkt en vastgesteld. Deze processtap houdt dan eigenlijk niet meer in dan: (1) het daadwerkelijk uitvoeren van de geplande V&V activiteiten door het IPM-team: ofwel het toetsen van het voorgeschreven ontwerp (met name de haalbaarheid van nieuw gemaakte ontwerpkeuzes) aan het voldoen van de systeemeisen die daarop van toepassing zijn en (2) het opnemen van alle specifieke V&V-voorwaarden bij de systeemeisen (voor in de VSE).
Output	✓

Ontwerpen en specificeren van het systeem S9 Beheren systeemspecificatie	
IPM-rol	TM
Doel	✓
Input	*Toevoeging*: - Scopewijzigingen in de POF incl. RUPS maatregelenlijst
Activiteiten	✓
Output	✓

4. Uitwerken contractspecificatie

Uitwerken contractspecificatie **C1 Bepalen oplossingsruimte contractspecificatie**	
IPM-rol	*Verduidelijking*: De verantwoordelijke IPM-rolhouder van deze processtap is de contractmanager (CM), echter is expliciet in deze processtap een grote ondersteuning nodig van de TM.
Doel	✓ (de '✓' staat voor geen toevoegingen/verduidelijkingen etc. op hoe het in de huidige procesbeschrijving beschreven staat)
Input	✓
Activiteiten	*Verduidelijking*: Moeilijkheden die worden ervaren in deze processtap m.b.t. het realiseren van oplossingsruimte hebben te maken met de toepassing hiervan. Oplossingsruimte is wenselijk omdat dit marktpartijen veelal vrijheid geeft om middels innovatie, goedkoop inkopen, slimme bouwfaseringen e.d. tot een binnen de randvoorwaarden optimale oplossing te komen voor het project, waardoor de opdrachtgever maximale waarde voor zijn geld krijgt. Echter moet deze oplossingsruimte worden gecreëerd m.b.t. het ontwerp, dit is dan de vrijheid waarin de marktpartijen ontwerpkeuzes kunnen maken (onafhankelijk van een hoog of laag detailniveau), ofwel ontwerpvrijheid. Oplossingsvrijheid moet daarentegen niet worden gecreëerd m.b.t. het contract zelf en heeft dus geen betrekking op vage systeemeisen of verificatiemethoden. Het is juist noodzakelijk dat de vraag en systeemeisen zo specifiek en meetbaar mogelijk vastgesteld zijn waardoor de kwaliteit gewaarborgd kan worden.
Output	✓

Uitwerken contractspecificatie **C2 Bepalen scope contractspecificatie**	
IPM-rol	*Verduidelijking*: De verantwoordelijke IPM-rolhouder van deze processtap is de contractmanager (CM), echter is expliciet in deze processtap een grote ondersteuning nodig van de TM.
Doel	✓
Input	✓
Activiteiten	*Niet van toepassing*: De activiteiten die betrekking hebben op het beheren van raakvlakken hoeven zelden in onderhoudsprojecten worden uitgevoerd (m.u.v. voor de SLOT's) (zie verklaring voorgaande processtappen) *Verduidelijking*: De scope van de contractspecificatie kan vanuit inkoopoverwegingen bijvoorbeeld worden verdeeld in twee percelen, hierdoor wordt het project als het ware onderverdeeld in twee projecten en daardoor ontstaan twee contracten. Met behulp van dit voorbeeld (de onderverdeling van het project in meerdere contracten) kan duidelijk worden gemaakt dat wel degelijk een verschil bestaat tussen de systeemspecificatie en contractspecificatie, dit wordt in de praktijk vaak niet herkend. In het geval van dit voorbeeld is namelijk sprake van maar één systeemspecificatie en, door de verdeling in twee percelen, sprake van twee contractspecificaties.
Output	✓

Uitwerken contractspecificatie C3 Samenstellen contractspecificatie	
IPM-rol	*Verduidelijking*: De verantwoordelijke IPM-rolhouder voor deze processtap, zoals in de huidige procesbeschrijving beschreven, is de TM. De TM levert het uitgevoerde werk, de VSE, aan de CM. De CM is daarna eindverantwoordelijke voor de samenhang van alle contractdocumenten. De samenwerking tussen de TM en CM is in deze processtap dus van groot belang.
Doel	✓
Input	*Toevoeging*: - Modellen voor aanbestedingsdossier (denk hierbij bijvoorbeeld aan VSE, VSP, annexen, inschrijvings- en beoordelingsdocument (I&B) etc.)
Activiteiten	✓
Output	*Toevoeging*: Door de verschillende type contractvormen in aanlegprojecten (D&C en DBFM contract) en onderhoudsprojecten (E&C en prestatie contract) verschilt de output per contractvorm, echter is de output altijd in de vorm van contractstukken en aanbestedingsdocumenten vormgegeven. - E&C contract: vraagspecificatie eisendeel (VSE) en procesdeel (VSP) - Prestatie contract: algemene vraagspecificatie

Uitwerken contractspecificatie C4 Controleren kwaliteit contractspecificatie	
IPM-rol	*Verduidelijking*: De verantwoordelijke IPM-rolhouder voor deze processtap, zoals in de huidige procesbeschrijving beschreven, is de TM. De TM levert het uitgevoerde werk, de VSE, aan de CM. De CM is daarna eindverantwoordelijke voor de samenhang van alle contractdocumenten. De samenwerking tussen de TM en CM is in deze processtap dus van groot belang.
Doel	✓
Input	*Toevoeging*: - E&C contract: vraagspecificatie eisendeel (VSE) en procesdeel (VSP) - Prestatie contract: algemene vraagspecificatie
Activiteiten	✓
Output	✓

BEGRIPPENLIJST

Begrip	**Definitie**	**Doel**
Verificatie	Bevestiging door de levering van objectief bewijs dat aan de gespecificeerde eisen is voldaan.	Het voldoen aan de gespecificeerde eisen. Ofwel: dat het 'juist' gebouwd/gespecificeerd is.
Validatie	Bevestiging door de levering van objectief bewijs dat aan de eisen voor een specifiek beoogd gebruik of specifiek beoogde toepassing is voldaan.	Het voldoen aan de klantbehoefte. Ofwel: dat het 'juiste' gebouwd/gespecificeerd is.
V&V	Alle activiteiten die nodig zijn om objectief en expliciet te kunnen aantonen dat de oplossing voldoet aan de eisen en behoeften van de klant en daarmee past binnen de oplossingsruimte.	
Klanteisenspecificatie (KES)	Document dat de klantvraag specificeert in termen van de benodigde functionaliteiten, de eisen per stakeholders, de beschikbare oplossingsruimte en een beschrijving van het system of interest van de klant.	
Systeemspecificatie (SYS)	Gestructureerd overzicht van het betreffende systeem, de beschikbare oplossingsruimte, een beschrijving van de benodigde functionaliteiten, de context van het systeem, de geïdentificeerde raakvlakken met (andere systemen in) de omgeving, de eisen gesteld aan het systeem alsmede een beschrijving van de gemaakte ontwerpkeuzes.	
Vraagspecificatie Eisendeel (VSE)	Contractdocument waarin de eisen aan het (deel)product zijn verwoord.	Het beschrijven van de aan het eindproduct gestelde eisen ('wat'-eisen).
Vraagspecificatie Procesdeel (VSP)	Contractdocument waarin de eisen aan de uit te voeren werkzaamheden zijn verwoord.	Het beschrijven van de aan het proces (van totstandkoming van het te realiseren eindproduct) gestelde eisen ('hoe'-eisen).
Vraagspecificatie (ofwel contractspecificatie)	Het zodanig in de basisovereenkomst aangemerkte contractdocument dat door of namens de opdrachtgever is vervaardigd, op basis waarvan de opdrachtnemer zijn aanbieding heeft opgesteld en ingediend.	Om de functionele vraag van de opdrachtgever aan de opdrachtnemer te duiden.

Appendix VII: Validation process model

Project manager: *Tohid Navabi*

Onderhoud specifieke knelpunten	Check	Gewicht	Score
Bureaucratie	☑	x1	*1*
Terminologie	☑	x1	*1*
Rolverdeling	☑	x1	*1*
~~Externe stakeholders~~	☐	x2	*n.v.t.*
~~V&V paragraaf~~	☐	x2	*n.v.t.*
~~V&V klant~~	☐	x2	*n.v.t.*
~~V&V systeem~~	☐	x2	*n.v.t.*
Ontwerpen	☑	x2	*2*
Analyseren project opdracht	☑	x2	*2*
			Max. score: *7*
			Score: *7*
			Eind score: *10*

Bonus:

Aanleg & onderhoud knelpunten	Check
~~V&V~~	☐
~~Specificaties 3x~~	☐
~~Controleren processtappen~~	☐
Algehele ontwerp procesbeschrijving	☑

Ofwel: is dit het product wat jullie nodig wensten en achtten?
Ja / ~~nee~~

Manager project beheersing: *Ad van Ginneken*

Onderhoud specifieke knelpunten	Check	Gewicht	Score
Bureaucratie	☑	x1	*1*
Terminologie	☑	x1	*1*
Rolverdeling	☑	x1	*1*
~~Externe stakeholders~~	☐	x2	*n.v.t.*
~~V&V paragraaf~~	☐	x2	*n.v.t.*
~~V&V klant~~	☐	x2	*n.v.t.*
~~V&V systeem~~	☐	x2	*n.v.t.*
Ontwerpen	☑	x2	*2*
Analyseren project opdracht	☑	x2	*2*
			Max. score: *7*
			Score: *7*
			Eind score: *10*

Bonus:

Aanleg & onderhoud knelpunten	Check
~~V&V~~	☐
~~Specificaties 3x~~	☐
~~Controleren processtappen~~	☐
Algehele ontwerp procesbeschrijving	☑

Ofwel: is dit het product wat jullie nodig wensten en achtten?
Ja / ~~nee~~

Technisch manager: *Youssef Hsaini*

Onderhoud specifieke knelpunten	**Check**	**Gewicht**	**Score**
Bureaucratie	☑	x1	*1*
Terminologie	☑	x1	*1*
Rolverdeling	☑	x1	*1*
~~Externe stakeholders~~	☐	x2	*n.v.t.*
V&V paragraaf	☑	x2	*2*
~~V&V klant~~	☐	x2	*n.v.t.*
V&V systeem	☑	x2	*2*
Ontwerpen	☑	x2	*2*
Analyseren project opdracht	☑	x2	*2*
			Max. score: *11*
			Score: *11*
			Eind score: *10*

Bonus:

Aanleg & onderhoud knelpunten	**Check**
V&V	☑
Specificaties 3x	☑
Controleren processtappen	☑
Algehele ontwerp procesbeschrijving	☑

Ofwel: is dit het product wat jullie nodig wensten en achtten?
Ja / ~~nee~~

Contract manager: *Reita Biere*

Onderhoud specifieke knelpunten	Check	Gewicht	Score
Bureaucratie	☑	x1	*1*
Terminologie	☑	x1	*1*
Rolverdeling	☑	x1	*1*
~~Externe stakeholders~~	❑	x2	*n.v.t.*
~~V&V paragraaf~~	❑	x2	*n.v.t.*
~~V&V klant~~	❑	x2	*n.v.t.*
~~V&V systeem~~	❑	x2	*n.v.t.*
Ontwerpen	☑	x2	*2*
~~Analyseren project opdracht~~	❑	x2	*n.v.t.*
			Max. score: *5*
			Score: *5*
			Eind score: *10*

Bonus:

Aanleg & onderhoud knelpunten	Check
~~V&V~~	❑
Specificaties 3x	☑
~~Controleren processtappen~~	❑
Algehele ontwerp procesbeschrijving	☑

Ofwel: is dit het product wat jullie nodig wensten en achtten?
Ja / ~~nee~~

SE adviseur: *Michel Boer*

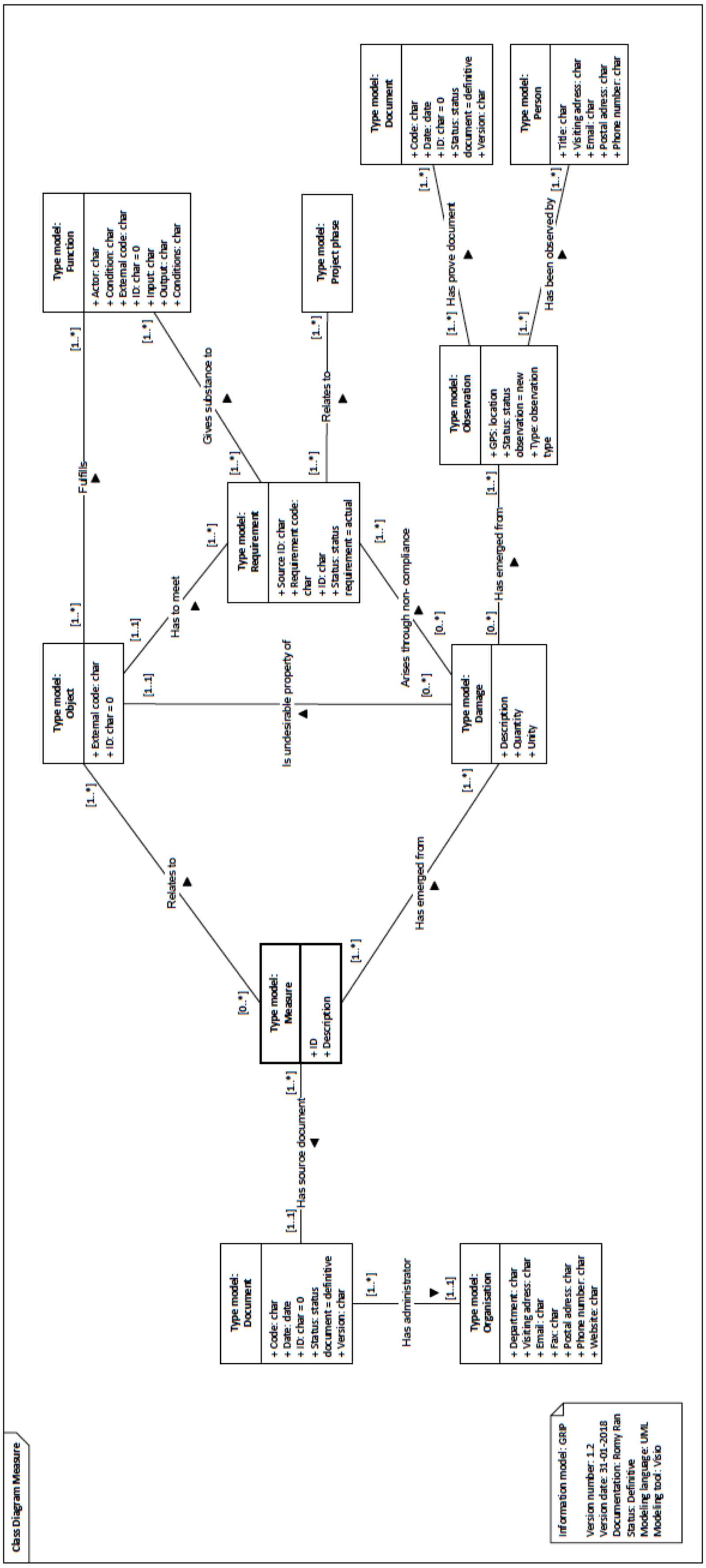
Onderhoud specifieke knelpunten	Check	Gewicht	Score
Bureaucratie	☑	x1	*1*
Terminologie	☑	x1	*1*
Rolverdeling	☑	x1	*1*
Externe stakeholders	☑	x2	*2*
V&V paragraaf	☑	x2	*2*
V&V klant	☑	x2	*2*
V&V systeem	☑	x2	*2*
Ontwerpen	☑	x2	*2*
Analyseren project opdracht	☑	x2	*2*
			Max. score: *15*
			Score: *15*
			Eind score: *10*

Bonus:

Aanleg & onderhoud knelpunten	Check
V&V	☑
Specificaties 3x	☑
Controleren processtappen	☑
Algehele ontwerp procesbeschrijving	☑

Ofwel: is dit het product wat jullie nodig wensten en achtten?
Ja / ~~nee~~

Appendix VIII: Information model



Appendix IX: Validation information model