Measuring Systems Engineering and Project Success

An evaluation of Systems Engineering practices and Project Success in a Dutch Civil Engineering Contracting Firm

Thesis Report
Final

Masters' in Civil Engineering and Management

Datum	01-06-2018
Type of document	Master's Thesis
Title	Measuring Systems Engineering and Project Success
Subtitle	An Evaluation of Systems Engineering Practices and Project Success in a Dutch Civil Engineering Contracting Firm
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Status	Final
Place	Enschede

Preface

This thesis report is the final product of the research project regarding Systems Engineering practices and Project Success. The research project was performed at Reef Infra. I developed a measurement tool in collaboration with Reef Infra and the University of Twente. By finishing this thesis report, I also completed the study in Construction Management Engineering at the University of Twente in Enschede. The experience and knowledge I have collected during my study will provide a solid foundation. I am really looking forward for pursuing a career in the construction industry.

I would like to thank a number of people who supported me during the research project. Firstly, I would like to thank Djim Witjes for providing the opportunity for a research project at Reef Infra. Djim helped me in staying on track and in applying the proper focus in both the research strategy and in writing the thesis report. Next, I would like to thank Harry Steenbergen and Bert Lankheet for providing the means to collect and analyze data. They provide contact information for collecting project documentation. Moreover, their knowledge and experiences inspired me to dig deeper and helped in understanding Systems Engineering as a process coordination method. Besides them, I would also like to thank both my supervisors at the University of Twente, dr.ir. R.S. de Graaf and dr.drs. J.T. Voordijk. They provided me with critical feedback and assistance in writing a proper thesis report.

Lastly, I would like to thank my girlfriend Marleen Schlömer and my family for their inexhaustible support. They helped me to stay motivated. I am positive about my final thesis and I hope you will enjoy reading my thesis.

Erwin Berghuis
Enschede, 1st of June 2018

Abstract

In the last decades, developing and sustaining large complex engineering systems have become more challenging (de Graaf, Voordijk, & van den Heuvel, 2016). To facilitate contracting firms in the Dutch construction industry in their ability to deliver these more complex projects, innovative procurement methods based on integrated contracts, using Uniform Administrative Conditions for Integrated Contracts (UAV-ic) such as Design-Build or Design-Build-Maintain, are used by large clients in the Dutch construction Industry (de Graaf, Vormer, & Boes, 2017; Makkinga, de Graaf, & Voordijk, 2018). The transfer of responsibility from clients to contracting firms for the project design creates the demand for contracting firms to control and review the quality of their own work. Design decisions and commitments have a great impact on project life-cycle cost and defective design is a major cause of contract claims and change orders during construction (Andi & Minato, 2003). de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017) argue for a transition to the SE way of working in the Dutch construction industry.

Reef Infra, a mid-sized Dutch contracting firm, finds it challenging to increase standardization, independency, and overall performance regarding their SE process and finds it also challenging to collect performance information to SE related tasks. SE is a relative new way of working, which leads to a lot of insecurity (within the organization), struggle and discussion between Reef Infra and their clients and between Reef Infra and their subcontractors. Reef Infra is looking for opportunities to measure their SE performance to find or identify opportunities for improvement. Measuring their SE performance enables them to target underperforming SE tasks. Alongside their wish to improve their SE application, Reef Infra also finds it challenging to collect performance information, specifically regarding SE tasks and how to relate this to common project success categories in terms of budget, schedule and quality. When they are able to quantify this relation, Reef Infra can prove that their control over the SE process contributes to common project success categories and that they can use that information for BVP tenders.

To identify solutions for these challenges a research project is conducted. The project is performed to answer the following research question:

> *How can a Civil Engineering Contracting Firm measure their Systems Engineering performance and how do these metrics relate to project success indicators budget, schedule and quality?*

In this research project, a measurement tool is developed and applied to measure SE performance and project success in terms of budget, schedule and quality. The goal of the research is to assist Reef Infra in their improvement of their SE process by measuring their SE application in projects under UAC-ic. In addition, how SE contributes to achieving project success indicators budget, schedule and quality, which are commonly used as BVP objectives, is also explored. The goal within the research is to advice Reef Infra how they can measure their SE application to improve their SE process and to relate the extent of SE application to project success indicators budget, schedule and quality. A case study research design is applied to develop and apply the measurement tool. Multiple cases were selected according to the one-phase screening approach of Yin (2014). There were two main sources of evidence to fill the measurement tool. First, an extensive document analysis was performed to provide initial results. Afterwards, unstructured interviews were conducted to fill gaps in the results and validate findings. A case study protocol was developed to ensure that within-case results are mutually comparable in the cross-case analysis.

Based on the results of the research, the relation between the extent of SE application and project success cannot be determined. Too little data points were gathered. Looking at the graphs (Figure 8, Figure 9 and Figure 10), there is no optimum in the extent of SE application in relation to project performance. It is unclear if a higher or lower extent of SE application could prevent such events from happening. The findings of Honour (2013) and Beasley and O'Neil (2016) cannot be confirmed, because no clear relation cannot be established. Moreover, in the cases many other

characteristics or events seem to affect the project success. To eliminate bias of such characteristics on the relation between the extent of SE application and project success, more assessments of projects using the measurement tool have to be conducted.

The results do however confirm that the extent of SE application is different in each project. Although, all projects score an average SE score within a range of approximately 10% because the maximum score was 66% and the lowest score was 56%. The results suggest that SE elements are in some projects not applied while in other projects the same SE elements were applied quite substantially. This means Reef Infra does not apply a comprehensive and standardized SE method in their civil engineering projects. There are multiple reasons for the extent of SE application. First, unclear and out of date SE procedures affect the extent of SE application. Second, the level of SE skill and knowledge affected the extent of SE application. Third, Reef Infra is highly dependent on the client for the extent of SE application. Establishing clear SE procedures, enhancing SE skill and knowledge and reducing client dependency could enable the contractor to properly assess the extent of SE necessary to realize project success. A contingency approach to SE in construction projects can prevent over- and underinvestment. Relating SE performance to project success, enables proper recognition of how much SE activity is enough. This aspect must be further explored to establish clear methods for recognition. The approach to SE must be corresponding with the characteristics of the project, otherwise SE does not provide value in the project. Although, the measurement tool developed in the research emphasizes the extent of SE process applied at the project level it does provide the contracting firm with the necessary information to target underperforming SE tasks. Overall, to ensure that the contractor is capable of approach SE as a flexible process and not to overemphasize on SE tools, it is important the contractor must establish clear SE procedures, enhance SE skill and knowledge and reduce client dependency.

To conclude, based on the qualitative case study research findings, the SE process framework is applicable to assess the extent of SE application at a civil engineering contracting firm. The output of the measurement tool provide contractors with vital information to improve their SE process. Moreover, three specific factors affecting the extent of SE application are derived from the results. Based on the results no clear relation could be established between the extent of SE application and project success in terms of budget, schedule and quality. However, the findings do suggest when more projects are assessed using the measurement tool a relation can be established and the bias effect of other characteristics and events that also affect project success can be eliminated. Therefore, Reef Infra benefits from further applying the measurement tool to assess the extent of SE application in their projects.

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List of Abbreviations

Abbreviation	**Meaning**
SE	Systems Engineering
System	A construction project concerned with improving the infrastructure in the Netherlands
RA	Requirement analysis
FA	Functional analysis
WBS	Work Breakdown Structure
SBS	System Breakdown Structure
RBS	Requirement Breakdown Structure
FBS	Functional Breakdown Structure
RL	Requirement Loop
DL	Design Loop
DVerifi	Verification Design phase
DValidi	Validation Design phase
RVerifi	Verification Realization phase
RValidi	Validation Realization phase
V&V	Verification and Validation
SMART	Specific, Measurable, Achievable, Realistic and Time-bound
Construction Project	A civil engineering project concerned with infrastructure, hydraulic engineering or concrete engineering
BVP	Best Value Procurement: a value based procurement method.
SME	Small and Medium sized Enterprise
Contractor	Main contracting firm responsible for project execution
RfA	Request for Adjustment, possible contract adjustment necessary after additional work is assigned to the project which was not part of the initial contract between client and contractor

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1 Introduction

In the introduction of this thesis report, the background (paragraph §1.1), problem owner (paragraph §1.2), the problem statement (paragraph §1.3), research goals (paragraph §1.4) and research questions (paragraph §1.5), the scope of the research (paragraph §1.6), the relevance (paragraph §1.7) and the reading guide (paragraph §1.8) are introduced and explained.

1.1 Background

In the last decades, developing and sustaining large complex engineering systems have become more challenging (Chan, Scott, & Chan, 2004; de Graaf et al., 2016). Many construction projects are characterized by a high degree of uncertainty and fragmentation in terms of jointed organizations and sub-contracting (Adriaanse, 2014; Locatelli, Mancini, & Romano, 2014; Makkinga et al., 2018). Complex projects are defined by several characteristics, according to Locatelli et al. (2014, p1397). Construction projects in general all meet these characteristics.

1. Several key distinct disciplines, methods or approaches involved in performing the project:
   - ⇒ Many different disciplines are involved ranging from architects, structural engineers, process managers, etc. (de Graaf et al., 2016; Makkinga et al., 2018).
2. Strong legal, social, or environmental implications from performing the project:
   - ⇒ Many construction projects are performed within the living environment of people (El-Rayes & Kandil, 2005).
3. Usage of most of partner's resources:
   - ⇒ Large part of the project is subcontracted to specialized subcontractors (Gadde & Dubois, 2010; Makkinga et al., 2018).
4. Strategic importance of the project to the organization or organizations involved:
   - ⇒ Many construction projects are performed to maintain transportation or accommodation, which make these project of strategic importance (Rijkswaterstaat, 2017).
5. Stakeholders with conflicting needs regarding the characteristics of the project:
   - ⇒ The client who pays for the project is in many projects not the end-user of the project. This often results in conflicting demands (Beasley & O'Neil, 2016).
6. High number of variety of interfaces between the project and other organizational entities:
   - ⇒ Most of the failure costs occur because of failure to manage interfaces in construction projects (ProRail, 2015; ProRail et al., 2013).

To facilitate contracting firms in the Dutch construction industry in their ability to deliver these more complex projects, innovative procurement methods based on integrated contracts, using Uniform Administrative Conditions for Integrated Contracts (UAV-ic) such as Design-Build or Design-Build-Maintain, are used by large clients in the Dutch construction Industry (de Graaf, Vormer, et al., 2017; Makkinga et al., 2018). The transfer of responsibility from clients to contracting firms for the project design creates the demand for contracting firms to control and review the quality of their own work. Design decisions and commitments have a great impact on project life-cycle cost and defective design is a major cause of contract claims and change orders during construction (Andi & Minato, 2003). de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017) argue for a transition to the Systems Engineering (SE) way of working in the Dutch construction industry. SE is applied to deliver successful projects in complex environments (INCOSE, 2006b). SE provides better systems in less time and cost with fewer risks by greater control over the system, its' design and realization (Honour, 2013). de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017) define the SE way of working as: *"Contractors' responsibilities transform from merely carrying out a predefined, structured assignment into solving an ill-defined, ill-structured and complex problem in an early stage of the project"*.

The value of SE seems widely accepted in the Dutch construction industry (de Graaf et al., 2016; de Graaf, Vormer, et al., 2017; Makkinga et al., 2018; ProRail, 2015; ProRail et al., 2013). SE is therefore broadly applied in Dutch construction projects using UAV-ic. Many contracting firms, such as Reef Infra, apply SE in their design and realization process (ProRail et al., 2013). The value of SE is, according to de Graaf (2014), greater satisfaction of interest, less rework, increased transparency, less resistance, less redesign and less failure costs. Overall, SE increases the likelihood of a project being delivered to budget and on schedule (Honour, 2013). SE is all about investing in pre-work, not rework (Beasley & O'Neil, 2016). However, contracting firms find it difficult to determine to what extent SE must be applied considering the project characteristics (Brekelmans, 2016; Reef Infra, 2018). Although, well established SE guidelines exist in the Dutch construction industry the SE approach on the project level seems different for public clients on different institutional levels (Rijkswaterstaat, provincial, municipality, etc.). Determining the appropriate system engineering management approach while considering project characteristics and type reduces the ultimate failure point in projects (Sauser, 2006). Understand what extent of SE is appropriate to realize the project successfully is still unexplored. The approach to SE depends on the practitioners own experience and knowledge of SE (Elliott, O'Neil, Roberts, Schmid, & Shannon, 2012). Reef Infra is highly dependent on the clients' approach to SE for their own SE process. Beasley and O'Neil (2016) also confirms this problem and finds that within the broader SE community this is becoming more an interest of discussion. Practitioners focus too much on the SE process. SE becomes merely a set of rigid tools which have to be applied in the every project. There is no clear sense of how SE improves project success.

That the value of SE is widely accepted but a clear understanding of how SE improves project success is missing, seems adverse. It seems more logic to first understand how SE relates to project success before the value of SE becomes clear in more detail and additional values can be derived. The most basic perception of project success is the Iron-triangle, according to Locatelli et al. (2014). A project is successful when it is delivered to budget, on schedule and conformance to clients' specifications. To increase the application of SE in the Dutch construction industry "sweet spots" must be derived (Beasley & O'Neil, 2016). Sweet spots tell practitioners something about the appropriate extent of SE application to enable the delivery of a successful project. To do so, the relation between SE and project success must be quantified.

Moreover, other developments in the Dutch construction industry are also accommodated by quantifying the SE application of a contracting firm and relate this to project success. Many contractors apply SE in their construction projects. Performance of SE thus becomes interesting in tender procedures under Best Value Procurement (BVP). Major clients in the Dutch construction industry embrace BVP to select the appropriate contracting firm (Rijkswaterstaat, 2016). One of the key ingredients of BVP is performance information. Based on performance information a contracting firm can prove they are able to realize the project objectives as they have done this in a similar project. The Iron-triangle's success indicators budget, schedule and quality are project success indicators commonly used in BVP (Booij, 2013; Horstman & Witteveen, 2013; Rijkswaterstaat, 2016). From a practical viewpoint, quantifying the extent of SE application and relate this to the project success indicators is necessary to be successful in BVP. This makes SE performance information increasingly interesting for contracting firms in the Dutch construction industry.

1.2 Problem owner: Reef Infra

Reef infra is a middle sized civil engineering contracting firm in the Netherlands and works on future mobility issues together with their customers. The organization consists of approximately 170 professionals working in two disciplines; road construction and concrete- and hydraulic engineering. Reef Infra is located in Groningen, Oldenzaal and Wijchen in the Netherlands and is a subsidiary of Strukton Civiel. Their mission is to realize smart solutions for better infrastructure networks in the Northeast of the Netherlands. Their local teams of professionals realize the need of users in small, big and integrated construction projects. Their aim is to seek interaction with the client to try to convert complex infrastructural challenges into fitting solutions as best as possible. Their vision is to be a warm and trustworthy organization where employees work with pleasure and clients see Reef Infra as a great partner, and all while being a locally involved contractor. Reef Infra stands for sustainable collaboration with benefits for all involved parties. They seek for market change and differentiate themselves from the competition with innovative solutions which have a social impact. In 2006 Reef Infra became a part of Strukton Civiel, which has a main office in Utrecht. Strukton Civiel develops, realizes and maintains large civil engineering projects from the conceptual phase until the exploitation phase. Strukton Civiel delivers (whatever the requirements are) complete and tailor made solutions for every phase of the construction chain. Strukton Civiel is a full service civil engineering contracting firm with eager to innovate, collaborate and a drive for team spirit.

1.3 Problem statement

Reef Infra finds it challenging to increase standardization, independency, and overall performance regarding their SE process and finds it also challenging to collect performance information to SE related tasks. Reef Infra is highly dependent on clients for the extent of SE application as clients determine for large parts how Reef Infra must apply SE in their projects. Reef Infra is also highly dependent on subcontractors because large parts of the work is subcontracted making subcontractors responsible for great deal of the input in Reef Infra's SE process. SE is a relative new way of working for clients and subcontractors. This leads to a lot of insecurity (within the organization of clients and subcontractors), struggle and discussion between Reef Infra and their clients and between Reef Infra and their subcontractors. Reef Infra is looking for opportunities to measure their SE performance to find or identify opportunities for improvement. Measuring their SE performance enables them to target underperforming SE tasks. Alongside their wish to improve their SE application, Reef Infra also wants to become more successful in BVP. To become more successful Reef Infra has to collect performance information. Reef Infra finds it challenging to collect SE performance information and how to relate these measurements to common project success indicators budget, schedule and quality which are commonly used in BVP tenders. When they are able to quantify this relation, Reef Infra can prove that their control over the SE process contributes to common project success indicators. This could provide interesting performance information which Reef Infra can use in BVP.

1.4 Research goal

In this research project, a measurement tool is developed and applied to measure SE performance and project success in terms of budget, schedule and quality. The models developed by de Graaf et al. (2016); de Graaf, Vormer, et al. (2017); Honour (2013) provide the foundation for this measurement tool. Honour (2013) developed a method to determine the SE effort necessary for program success in terms of cost, planning and technical quality. de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017) developed a method to measure SE performance in a Dutch Water board and civil engineering consulting firm. The measurement tool developed in this research project fills the gap in literature by adding the perspective of a Dutch contracting firm, enabling an industry wide evaluation of SE. Also, the results of this research can be compared to the results of Honour (2013) to analyze how well the Dutch construction industry performs SE compared to other industries.

Goal of the research

The goal of the research is to assist Reef Infra in their improvement of their SE process by measuring their SE application in projects under UAC-ic, which enable them to specifically target underperforming SE tasks. In addition, how SE contributes to achieving project success indicators budget, schedule and quality which are commonly used as BVP objectives is also explored. This exploration can provide Reef Infra with necessary knowledge to properly assess what extent of SE application is necessary to achieve project success in terms of budget, schedule and quality performance.

Goal within the research

The goal within the research is to advice Reef Infra how they can measure their SE application to improve their SE process and to collect SE performance information regarding project success indicators budget, schedule and quality.

1.5 Research questions

This paragraph summarizes the research question and sub questions which all together are going to provide the necessary knowledge to meet the goal of the research. The general research question is subdivided into several sub questions. These sub questions provide structure in this study and safeguard the validity of this research.

Table 1: Overview of the general research questions and sub questions.

Research question	*How can a Civil Engineering Contracting Firm measure their Systems Engineering performance and how do these metrics relate to project success indicators budget, schedule and quality?*
Sub questions	1. How can the performance of Systems Engineering be measured? 2. How can project success indicators budget, schedule and quality be measured? 3. Which link is there between Systems Engineering metrics and project success indicators budget, schedule and quality? 4. To what extent can this link be clarified and understood?

1.6 Scope of the research

The scope of the research is important to ensure that the correct focus is maintain throughout the research to in the end answer the research questions. The scope of the research is divided into the research scope and the case study selection criteria.

1.6.1 Research scope

1. Only civil engineering construction projects are part of the research.
2. Only the relation between SE application and Project Success in terms of Budget, Schedule and conformance to clients' specification is under investigation in the research. Other project management techniques or project success indicators are left out of the research.
3. Only the extent of SE application is measured from the contractor's perspective.
4. Budget and schedule performance are explicitly measured in terms of actual budget/schedule compared to planned budget/schedule. This enables cross-case analysis of the results. However, such "performance factors" do not actually represent the profitability of the project from a contractor's perspective.
5. Only the SE application of a contracting firm is being analyzed in the research. That some parts of the SE application are outsources is left out of the scope.

1.6.2 Case study selection

1. The main contractor in the project must be Reef Infra or Reef Infra in combination with Strukton Civiel.
2. A variety of types (hydraulic or concrete engineering, infrastructure, area development, etc.) of projects are chosen to provide a comprehensive overview of the application of SE.
3. The used contract in the project is based upon UAC-ic.

4. The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
5. The main contractor applied SE.
6. There is enough documentation available to analyze the application of SE. At least a Verification and Validation plan and report are available.

1.7 Importance of this research project

In this section the importance of this research project is explained. This research project will not only contribute to the performance of Reef Infra but it also add to the existing body of knowledge by filling the gap in the literature by complementing to previous research of de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017). The research importance is subdivided into two categories: scientific relevance and practical relevance.

1.7.1 Scientific relevance

Studies addressing the application of SE in the civil engineering industry are mostly based upon case studies of large and complex projects (Beasley, 2017b; Elliott et al., 2012; Locatelli et al., 2014; ProRail et al., 2013). The use of SE in smaller and less complex construction projects is unaddressed in the scientific literature. de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017) performed an evaluation of the application of SE at a medium size consulting engineering firm and a Dutch water board, which could be classified as a medium sized client. Yet, an evaluation of the SE application at a medium size contracting firm has not been done before. The only evidence of evaluation of the SE application at medium sized projects is the research conducted by Wiesner, Nilsson, and Thoben (2017) and O'Connell, Wirthlin, Malas, and Soni (2013) (conducted a search query in relevant scientific journals: "Systems Engineering and "Small and Medium sized Enterprises (SME)"). They studied the application of SE in medium to small sized projects, but they did not address the Dutch civil engineering industry. Wiesner et al. (2017) studied just the application of the Requirements Engineering (a part of the SE methodology) in projects of industrial SMEs and O'Connell et al. (2013) studied the application of SE in US Air Force Small Business Innovation Research (SMBIR) projects. They found failure to implement good SE principles due to limited resources and competences at these SME leading to performance short falls. So, therefore this research complements the research of Wiesner et al. (2017) and O'Connell et al. (2013) by studying the complete application of SE in small or medium sized projects in another industry.

This research also complements the research done by de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017). de Graaf et al. (2016) preformed an analysis of the SE process at a Civil Engineering Consulting firm. They concluded that the SE process should be improved by establishing procedures and responsibilities, knowledge and skills of employees and supporting the client in applying SE. de Graaf, Vromen, and Boes (2017) performed an analysis of the SE process at a Dutch Water board. Their main conclusions were that the SE process should be improved by ensuring management support for SE, improve SE skills and knowledge and establishing clear SE standards and procedures. This research fills the gab in their research as the SE process of a main contractor is analyzed and enables the opportunity for a cross industry analysis of the application of SE in the Dutch civil engineering industry.

Furthermore, there is a lot attention in scientific literature addressing the application of BVP in the civil engineering industry (Rijkswaterstaat, 2016; Rijt & Santema, 2012; Snippert, Witteveen, Boes, & Voordijk, 2015; Yu & Wang, 2012). Elyamany, Abdelrahman, and Zayed (2012), Yu, Wang, and Wang (2013) and Booij (2013) done research on the contractors' perspective in offer development in BVP tenders and Jongerius (2014) initiated research on quantifiable performance information in BVP tenders. This research adds to previous research on performance information in BVP tenders by investigating how SE metrics provided by the SE framework can be link to project success metrics which are commonly used in BVP tenders.

1.7.2 Practical relevance

This study explores the application of SE in medium size construction projects at a medium size contracting firm in the Dutch civil engineering industry. A measurement tool initiated by de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017) is further developed, modified and applied to produce SE performance information and relate this information to project success in terms of budget and schedule performance and quality.

The practical relevance of this study is twofold. First of all, in the first part of this research improvements of the SE process at the contracting firm are generated and implementation of these improvements are suggested. To come up with these improvements the application of SE is measured. Second of all, in the second part of this study the SE metrics are analyzed and linked to project success in such a way that the contracting firm can apply the metrics in BVP tender procedures to provide evidence for meeting these commonly used BVP objectives. Moreover, suggestions are made to develop a method to determine the extent of SE while also considering project characteristics.

1.8 Reading guide

The next part of the thesis consists of four subparts. In chapter 2, the theoretical framework is presented. This subpart presents a reflection on scientific literature on Systems Engineering and Project success in the context of the Dutch construction industry. In chapter 3, the research method is explained and accounted for. After the research method, the results of the research are presented in chapter 4. For each case, the specific SE metrics and project success metrics are presented. The results are analyzed and discussed in chapter 5. Important empirical findings are linked to theory. Lastly, in chapter 6 the conclusions and recommendations are explained. The main research question is answered and the recommendations for both Reef Infra and future research are discussed. The appendices come after the final chapter 6. The appendices consists of the quick scan (Appendix 1), the case study protocol (appendix 2) and the case study report (appendix 3).

2 Theoretical framework

2.1 Introduction

In this research project a measurement tool is developed which quantifies the extent of SE application and Project Success indicators. By quantifying the extent of SE application and link this to project success in terms of budget, schedule and conformance to client's specifications, Reef Infra enables opportunities to target underperformance SE tasks while simultaneously providing evidence to showcase how their SE performance improves the project success in terms of these indicators. Therefore, the pillars of this research project are:

1. Systems Engineering in the Dutch construction industry context:
   a. SE principles;
   b. Barriers for implementing SE;
   c. SE elements;
   d. SE values.

2. Project success indicators:
   a. Budget performance;
   b. Schedule performance;
   c. Conformance to specification.

The research model displays the presumed relationship between SE performance and project success indicators (Figure 1).

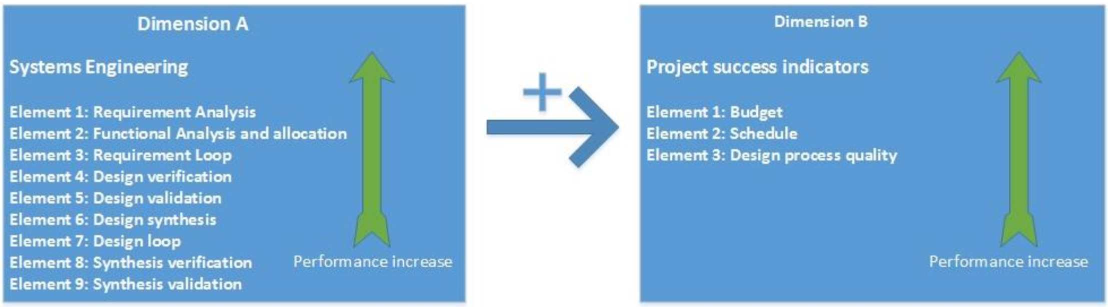

Figure 1: Research model.

First the two dimensions of the framework are explained in more detail (paragraph §2.2 and paragraph §2.3). Finally, the integrated theoretical framework is clarified (paragraph §2.4).

2.2 Dimension A: Systems Engineering

In this paragraph, the SE process is broken down into measurable elements. This is done based on the framework of de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017). First the SE way of working is described. Next, the measurable elements of SE are presented. Lastly, the value of SE is described to initiate the connection between the two dimensions of the research model.

2.2.1 SE way of working

The International Council on Systems Engineering defines Systems Engineering as an interdisciplinary approach and means which considers the business and technical needs of all customers in realizing successful systems (INCOSE, 2006a). In the ISO/IEC/IEEE 15288:2015 a more complete definition can be found: *"systems engineering is an interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholder needs, expectations, and constraints into a solution and to support that solution throughout its life"* (ISO, 2015, p.10). Complexity and change of systems can effectively be managed by applying

SE (INCOSE, 2006b). Construction projets become more complex, according to (de Graaf, Vormer, et al., 2017). Contractors have to solve ill-defined, ill-structured and complex problems (de Graaf, Vormer, et al., 2017). This development is happening while (INCOSE, 2006b) confirmed that during the design process decisions are made determining 80% of the life-cycle costs of a project. For contractors it is increasingly important that they are capable of developing effective design solutions. Considering the changing nature of construction projects, de Graaf et al. (2016) argue for the transition to the SE way of working in the Dutch Construction industry. The SE way of woking provides additional effort to the conceptual phase by concept exploration and design (INCOSE, 2006b). This creates numoerous benefits over the traditional way of working. These benefits are presented in paragraph §2.2.3.

First, the SE way of working is further elaborated by describing the principles and the barriers for implementing SE successfully. Combined industry effort has resulted in guidelines which are based upon these principles (ProRail et al., 2013). In this guideline, some SE best practices and barriers to proper implementation are mentioned. The principles and barriers help in establihsing the framework for SE application. The elements which are part of the framework are based on these principles. Moreover, by understanding the barriers for implementation a more indepth understanding of the SE application is established.

2.2.1.1 Principles of SE

When SE is applied in projects some principles must be considered to successfully apply SE. These principles provide guideline and structure to the SE application. The following principles should be considered (ProRail et al., 2013):

- Know the client's demands and wishes;
- Systems Thinking;
- Transparency;
- Efficiency;
- Balance design freedom and contractual agreements;
- Verification and validation;

The principles provide foundation for the framework, which structure the measurement tool developed in this research project. Therefore how these principles provide guideline for the SE way of working is explained more in-depth.

Principle 1: Know the client's demands and wishes
When applying SE the problems and opportunities related to the client's needs regarding the project are analyzed. This analysis is done to specify client's needs into demands, which is structured in the Customer Requirements Specifications (CRS). Whilst the system constantly develops, it is important that changes in client's needs or demands are taken into account regarding the fine-tuning of the system. SE makes it possible to develop the best possible solution for a problem within the given space available for solutions regulated by client's needs and demands (ProRail, 2015; ProRail et al., 2013). The client is the one who specifies the problem, the available space for solutions and if a solution is appropriate to solve the problem at hand. The CRS is input for the continuing development process of the system.

Principle 2: Systems Thinking
First and foremost, SE is an approach which realizes systems that meet a set of requirements. A system is according to (ISO, 2015, p.9) *"a combination of interacting elements organized to achieve one or more stated purposes".* This approach of realizing a system that meet a set of requirements is originating from "Systems Thinking". The definition of systems thinking is that a system consist of objects and is always part of a greater whole and must realize a set of goals (ISO, 2015; ProRail et al., 2013). In the Dutch civil engineering industry the project is divided into specific subparts which are then subcontracted to subcontractors who are specialized in the specific

subparts. Hence, the focus is on the sub-system level in projects. This focus makes it unable to cope with the increasing complexity of projects, strong variety of interfaces, the interdependence of specialist techniques and the way of working of organizations (Locatelli et al., 2014). Systems thinking requires a multidisciplinary iterative approach to problem solving (Locatelli et al., 2014). Kapsali (2011) concluded in her research that systems thinking positively relates to the governance of innovativeness, complexity and uncertainty due to increasing the flexibility in managerial activities. She argues that projects benefit from a more iterative approach (i.e. Systems Thinking) instead of conventional project management approaches targeted to make the process of a project predictable enough to be managed (Kapsali, 2011). The systems thinking approach is further broken down into three subprinciples.

SE is an iterative process

Construction projects are often complex systems consisting of many objects. An iterative process is required to successfully realize such complex systems. Part of the SE process is to iterate between requirements, functions and design solutions (ProRail et al., 2013). The design solution of one object requires additional analysis of the complete system because this design solution impacts the design of connected objects. These additional analysis are eventually providing detailed specifications of the system as a whole and the objects as part of the system. The iterative process enable designers to created detailed specifications of design solutions.

Interdisciplinary

Construction projects are often divided according to the involved disciplines (civil, mechanical installations, electrical installations, etc.). However, by dividing the system the connection between parts of the system is often overlooked. In complex projects allot of different disciplines are involved over a number of system parts. An interdisciplinary approach to the design of the system and its realization prevents problems occurring on interfaces (where different disciplines overlap) between system parts (ProRail et al., 2013).

Life-cycle approach

Every construction project has a life-cycle from concept to development, realization, in use, maintenance and eventually demolition. Smart solutions for cheaper maintenance can be incorporated in the design when the life-cycle approach is applied during the design phase. When the focus is just on one phase of the life cycle, the system will only be optimized for that phase (ProRail et al., 2013).

Principle 3: Transparency

The SE way of working is transparent because decisions and the reasons underlying the decision are recorded demonstrable. The system must meet the client's requirements. Decisions made in the design phase enable the system to meet these requirements. To explicitly verify that the system meet these requirements, decisions regarding its' design must be recorded (ProRail et al., 2013). This is according to the Decision management process of (ISO, 2015).

Principle 4: Efficiency and effectivity

SE increases efficiency by structuring the design process. SE increases effectivity of the design process because iterative tools ensure "fit-for-purpose" (ProRail et al., 2013).

Principle 5: Balance design freedom and contractual agreements

"Freedom of design" is often causing discussion between clients and contractors. Every project is a solution with a certain degree of design freedom for client's demands and wishes. Clients and contractors often have a different perspective of the available design freedom. This is often a tradeoff between costs, duration and ensuring that all requirements are met to an extent that the client agreed upon. The contractor is responsible for developing a solution which fits the design freedom (ProRail et al., 2013).

Principle 6: Verification and Validation
The objective of verification and validation is to provide evidence of the system meeting its' requirements. By means of feedback process, it is ensured that the realized system meet the by the client's prescribed system (ProRail et al., 2013).

2.2.1.2 Barriers to implementing Systems Engineering

Elliott et al. (2012) defined multiple barriers to the application of SE in civil engineering projects regarding the discipline rail:

- nature of the industry;
- nature of SE itself;
- differences in traditions.

First of all, traditionally SE is applied on new systems (Elliott et al., 2012). In projects concerned with improvement of infrastructure the objective is in general to renovate or maintain current infrastructure to these days' standards. There are significantly less projects were new roads are developed (Rijkswaterstaat, 2017). Hence, other infrastructure projects are comparable to rail projects which are known for making changes to existing systems (Elliott et al., 2012). Moreover, in the SE application there is little attention given to short-term interruptions of current systems while these systems are being upgraded to current day standards. This is a major challenge in rail projects as Elliott et al. (2012) explains. This is also the case for infrastructure projects because most of the projects are also concerned with renovation or maintenance of infrastructure which is still being used at the time of renovation or maintenance. Often information about the current nature of the infrastructure is not always fully accessible/complete or correct. Therefore, the state of the current system is unclear making it increasingly challenging to complete the two tasks which come first in the SE process (de Graaf, 2014). SE proclaims pre-work not re-work. If the two main analysis of SE cannot be completed because information is missing, subsequent SE tasks are affected as well because of the iterative nature of SE.

Furthermore, a lot of the SE activities overlap with existing disciplines in a project. Elliott et al. (2012) argue that topics addressed in the SE methodology overlap with specific tasks which used to be assigned to project managers, engineers and architects. SE responsibilities are scattered among these well established and demarcated roles of the project team. This results in possible conflicts between the systems engineer and these well-established roles when similarities in responsibilities and expertise clash (Elliott et al., 2012). Moreover, were SE overlaps with well-established roles the perceived added value of doing it according to the SE way of working is often a point of discussion (Beasley & O'Neil, 2016). The Systems Engineering has to provide specific evidence of why the SE way is the better choice compared to the well-established work procedures. SE has in some way be "sold" to these well-established roles (Beasley & O'Neil, 2016).

Second of all, there is no precise agreement on the way SE should be organized in construction projects due to differences in opinion on the extent and structure of SE (Elliott et al., 2012). The extensiveness of the application of SE often changes from project to project. This is mostly the case because the application of SE in a construction project does not actually add to the delivery of any components of the project itself. The application of SE is concerned with how other disciplines deliver certain parts of the project. By assisting and guiding other disciplines their delivery is improved, resulting in an overall improved project. Hence, the benefits of SE are not directly independently visible in a project but merely "hidden" in the improvement of deliveries of parts of the project. This also explains why it is so important that SE is well established in the complete organization. To effectively improve the delivery of other disciplines it is necessary that these disciplines have a workable understanding of SE (Elliott et al., 2012, p.207). This is also one of the conclusions of the research of de Graaf et al. (2016). Their findings suggest that there are no clear internal procedures and responsibilities established and captured regarding the application of SE.

To add to this, SE is perceived to be adding overhead instead of value in projects. This reputation commenced due to its application in military and aerospace projects (Beasley & O'Neil, 2016). This perception is caused by multiple reasons. In the first place, complex SE specific jargon, such as Solution Synthesis, cause unfamiliarity which poses barriers and aversion to SE (Elliott et al., 2012). The construction industry has strong institutional culture and is often reluctant to change (Rivera, Le, Kashiwagi, & Kashiwagi, 2016). This makes it challenging to see past unfamiliar jargon. In the second place, over emphasis on SE process makes the SE process the replacement for Systems Thinking, one of the main principles of SE, and thus practitioners of SE become overly inclined to apply every SE activity prescribed in their SE process. Practitioners then find it difficult to in recognize which activities to perform and with what degree of rigor, all in all to realize value delivery in the project (Beasley & O'Neil, 2016). In the third and final place, there is too much emphasis on acquiring SE tools without acquiring the corresponding skills to apply the tools appropriately and effectively in the projects.

Honour (2004, p.2, in Elliott et al., 2012, p.206) explains: *"In many ways we understand less about systems engineering than any other engineering discipline".* Change in the industry take time to master and integrate into an organization. SE is a new way of approaching a project which also brings a new vocabulary. Elliott et al. (2012) and Beasley and O'Neil (2016) argue that one of the barriers for implementing SE is the language of SE. There are allot of tools with unfamiliar names and terms and even some known terms are used differently than their naming would suggest. This is also one of the major findings of de Graaf et al. (2016). They argue that the learning curve is steep, hence allot of effort is necessary to fully master the application of SE. Knowledge in these organizations is often spread ad-hoc, which strengthens the barrier of learning to implement SE properly.

Now that the principles of SE and barriers for implementation of SE are described, the foundation is laid to begin breaking down the SE way of working into measurable elements.

2.2.2 SE measurable in construction industry context

de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017) developed based on an SE process framework a measurement tool which measures the SE performance in construction projects. The framework is adjusted to the SE process of a contracting firm. These adjustments make the tool suitable to measure the extent of SE application and project success in terms of budget and schedule performance and conformance to client's specification of a contracting firm.

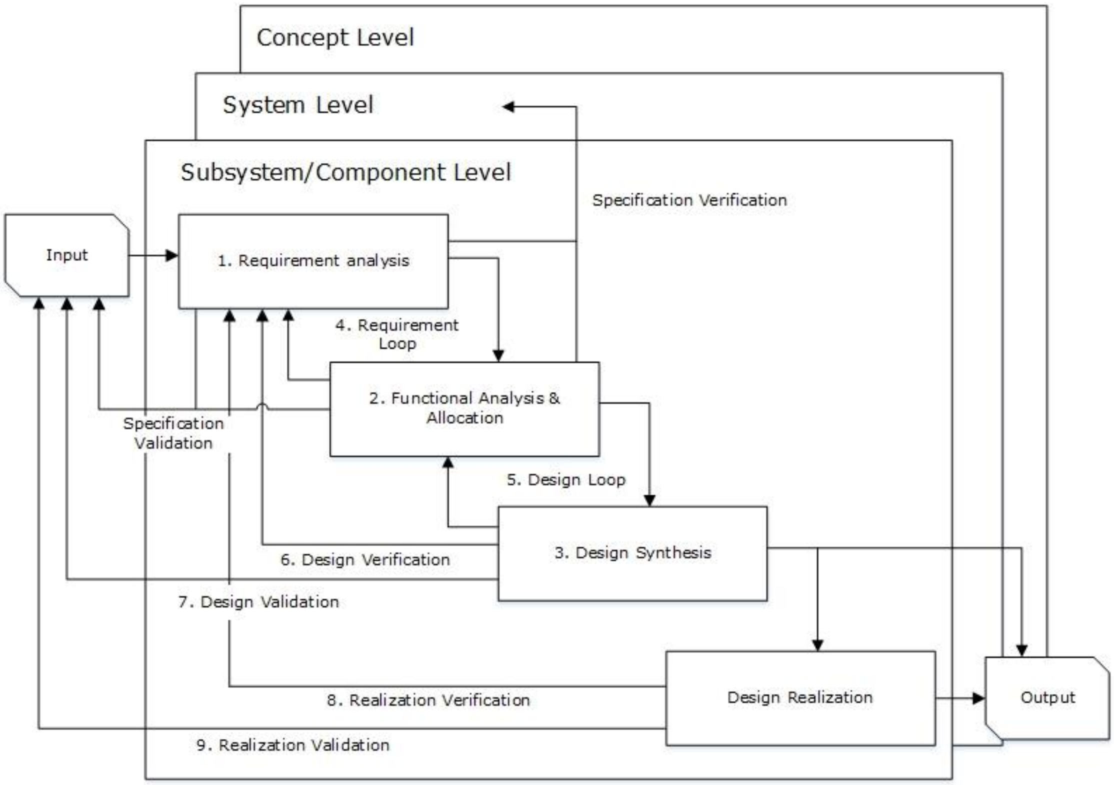

Figure 2: SE contractors process Framework based on INCOSE (2006a), ProRail et al. (2013), de Graaf (2014), de Graaf et al. (2016), de Graaf, Vormer, et al. (2017) and ISO (2015).

In the table below, we summarized the 9 measurable basic elements as part of the dimension A: Systems Engineering Performance of the research model.

Table 2: Overview of dimension A of the research model.

Dimension A: Systems Engineering Performance		Part of process
Element #1	Requirement analysis (RA)	Base process
Element #2	Functional analysis and allocation (FA)	Base process
Element #3	Design Synthesis (DS)	Base process
Element #4	Requirement Loop (RL)	Feedback process
Element #5	Design Loop (DL)	Feedback process
Element #6	Design verification (DVer)	Feedback process
Element #7	Design validation (DVal)	Feedback process
Element #8	Realization verification (RVer)	Feedback process
Element #9	Realization validation (RVal)	Feedback process

Element 1: Requirement analysis

The first core element of the SE process is the requirement analysis (RA). This analysis is done to define what the system must do and how well it is supposed to be doing this. This element describes the translation of client and stakeholders demands and needs to measurable requirements. Output of this analyse is a verification and validation plan. In this plan the project team describes how, when and by whom specific requirements are verified and validated during the project. Points of attention in this analysis is the use of some sort of hierarchical system for distinguishing importance of requirements, the traceability of these requirements and if requirements are SMART formulated. To measure the performance of a system, it is very important that these requirements are formulated SMART.

Element 2: Functional analysis and allocation
The second core element of the SE process is the functional analysis and allocation (FA). This analysis is done to define the functionality of the system and these functions must be combined in the Functional Breakdown Structure (FBS). The functionality of the systems describes what the system should do based on the measurable requirements and not how it should perform its functions. These functions are then coupled to objects which when combined form the system breakdown structure (SBS). Object specifications at least contain the measurable requirements, functions and interfaces related to the object. These objects are then combined with activities and from all together the Work Breakdown Structure (WBS). Point of attention in this analysis is if functions could be traced back to the measurable requirements.

Element 3: Design synthesis
The third core element of the SE process is the design synthesis analysis. This analysis is done to transform objects of the function analysis to design solutions. Each object, and therefore the design solutions, should meet its function and requirements determined in previous basic elements of the SE process. The design choices should be based upon traceable solution choices including the considerations of these choices. Points of attention in this analysis is how design choices are made and how changes in these choices are documented.

Element 4: Requirement loop
The functional analysis could set a different light on the requirement analysis which makes it necessary to execute the requirement analysis once again. This possibly could result in new insights into the requirements and thus the functions of the system and its coupling with objects. The fourth basic element of the SE process is therefore an iterative requirements loop between the first two basic elements of the SE process. Point of attention is that adjustments based on the requirement loop are recorded demonstrable.

Element 5: Design loop
The synthesis analysis should be performed multiple times as the design is always being optimized. The design solutions are being aligned with the requirements, functions and objects based upon needs from client and stakeholders. During this alignment it could become clear that functions must be added or altered therefore revising the function analysis. When the functional analysis is revised then the requirement loop must be performed a well. This means the SE process is followed multiple times. Point of attention in this analysis is if changes to functions and objects are properly documented and if adjustments are recorded demonstrable.

Element 6: Design verification
The sixth basic element of the SE process is the requirements/functions/objects verification. This verification and validation is done to provide demonstrably that the design solutions meet all the requirements, moreover meeting the needs and expectations of the client and stakeholders. As the SE process is an iterative engineering process with multiple loops any deviations will lead to adjustments in requirements, functions, and objects and eventually design solutions. This iterative engineering process is documented in a verification and validation plan. Necessary adjustments of design solutions, requirements, functions or objects should be formulated in a verification report. Point of attention in this verification is if these results and necessary adjustments are in some way documented and if requirements, functions or objects are traceable updated/changed.

Element 7: Design validation
The seventh basic element of the SE process is the requirements/functions/objects validation. This validation is done to check if design principles are in line with the client's and other stakeholders' expectations. Necessary adjustments of design solutions, requirements, functions or objects should be formulated in a validation report. Point of attention in this validation is if these results and necessary adjustments are in some way documented and if requirements, functions or objects are traceable updated/changed.

Element 8: Realization verification
The eight basic element of the SE process is realization verification. This verification is done to check if the realized objects meet the requirements and are according to the design plans. The additional benefit is that contractors properly document all the available information about the project in as-built documentation. Output of this task is a verification matrix with at least the following items:

- Verification moment;
- Verification method;
- Person responsible;
- Verification result;
- Define output documentation.

The contractor should pay explicit attention to possible adjustment to objects when requirements cannot be met. Adjustments must always be properly documented. Point of attention in this verification is if these results and necessary adjustments are in some way documented.

Element 9: Realization validation
The ninth basic element of the SE process is the realization validation. This validation is done to check if the realized objects not only meet requirements/functions and objects but more importantly the expectations of the client and other stakeholders. The validation must be performed based on a validation plan. The following items must be explicitly mentioned in the validation plan:

- Objects being validated;
- Validation method;
- Person responsible;
- Validation result;
- Define output documentation.

Point of attention in this validation is if these results and necessary adjustments are in some way documented.

Additional elements
Alongside these nine basic elements, de Graaf et al. (2016); de Graaf, Vormer, et al. (2017) defined additionally three supporting elements; Process input (Element 10), Process output (Element 11) and System analysis & control (Element 12). A contracting firm performs out of the three supporting elements only the Element 11. In many occasions the client or the administrator of the project performs Elements 10 and 12. In many projects, the client executes Element 10 when they provide an already extensive list of requirements. Also, the contracting firm only provides the tools for systems analysis and control (Element 12). After the realized objects are verified and validated, the objects are delivered to the client. The client then hands the project to the administrator of the project. The actual execution of systems analysis and control lies by the administrator of the project.

2.2.3 Value of SE in construction industry context

SE is a process oriented discipline that can deliver value (Beasley & O'Neil, 2016). This value of SE seems widely accepted in the construction industry, although on the project level the application of SE is depending on the practitioners' perspective, their skills and experience (Brekelmans, 2016). Standardization in the application of SE is therefore challenging (de Graaf et al., 2016; de Graaf, Vormer, et al., 2017; Makkinga et al., 2018). The common perception of SE value is provided by two basis rules, a greater emphasis on design and early risk reduction. According to Honour (2013), *"a greater emphasis on design creates easier, more rapid integration and test. The overall result is a savings in both time and cost, with a higher quality system product"* and *"a reduction of* *risk early prevents problems of integration and test for occurring, thereby reducing cost and shortening schedule"*. When applied properly, SE is believed to enable the delivery of a complex system with the demanded functionality on time and to budget (Beasley, 2017a; Elliott et al., 2012; Honour, 2009; Nederland, 2010). (Beasley, 2017b, p.6) summarizes some main benefits of SE:

- Understanding all stakeholder views - ultimately giving full lifecycle consideration and an alignment of all interests;
- Structured architecture, designing sub-systems and elements in the context of the whole - optimising the whole not the parts;
- Clear focus on requirements – both for verification and validation of the solution, and for decision rationale;
- Recognizing key issues, uncertainties and risks early in lifecycle, so there can be pre-work not re-work to prevent cost and schedule over-runs;
- Focus on purpose rather than purely the solution object.

The overall perception of the value of SE can be broken down into several categories, according to the de Graaf (2014). These categories are summarized below and linked to the main benefits of SE according to (Beasley, 2017a):

1. Increased satifisfaction of interests: achieved by understanding all stakeholder views;
2. Less resistance: achieved by focus on purpose rather than purely the solution object;
3. Increased transparancy of work procedures: achieved by structured designing of sub-systems and elements;
4. Less redesign of design solutions: achieved by clear focus on requirements;
5. Less rework: achieved by recognizing key issues, uncertainties and risks early;
6. Less failure cost: achieved by recognizing key issues, uncertainties and risks early.

2.2.3.1 Increased satisfaction of interests

In many construction projects, the realized objects solely meet the requirements and wishes of the client. Other stakeholders' requirements and wishes are often left out of the scope of the development process. This could potentially provide realized objects which perfectly fulfill the by the client proposed functions, but not in the eyes of the end-user (which is many times not the client). For example, additional requirements had to be incorporated after unexpected operations and maintenance stakeholders came to check for operational acceptance. This contributes to varied expectations for the performance of the system and the functions it has to fulfill (Beasley & O'Neil, 2016). When SE is applied, requirement management ensures that all stakeholders' requirements are collected and analyzed. The realized objects therefore meet as much stakeholders' requirements and wishes as possible.

2.2.3.2 Less resistance

In many construction projects, permits have to be issued to provide the legal basis for realizing the project. Stakeholders can issue opinions or protests in obtaining these permits. If this is the case, official procedures have to be followed. These procedures often hamper project progress and therefore create additional costs for the project. When SE is applied, all the stakeholders are actively informed and involved in the development process. This creates foundation for decisions and reduces opposition in stakeholders.

2.2.3.3 Increased transparency of work procedures

The design process in construction projects is often subcontracted to specialized design parties or architects. The external party translates requirements to design drawings. This translation is often a black box because the creative process were tradeoff decisions are made is only insightful for the external design party. Just the input, in terms of requirements, and the output, in terms of design drawings, are visible for the contracting firm. This makes the design process difficult to manage (de Graaf, 2014). SE improves the manageability of the design process in multiple ways. Design solutions are discussed and recorded in multidisciplinary teams. All requirements are analyzed, structured and the connection between requirements is established. Lastly, the explicit connection between requirements and design solutions makes verification and validation of the design transparent and imitable (de Graaf, 2014).

2.2.3.4 Less redesign

In construction projects the design is often complex and therefore difficult to do the first time right. Redesign is often necessary to increase appropriateness of the design and to solve design errors. de Graaf (2014) explains that in construction projects, too many redesigns are necessary to provide an appropriate design. Redesigns cost time and money. Redesigns are caused by a strong focus on design drawings and an incomplete overview of the requirements which the design has to meet (de Graaf, 2014). Design drawing are supposed to be representation of decisions made up until the point in the process during which the design drawing are finished. When these are based on incomplete requirement overviews, the chance of redesigns are high. This could potentially lead to adjustments in the contract between client and contractor. Such contract adjustments are almost always harmful for the entire project (de Graaf, 2014). When SE is applied, it is supposed that less redesigns are necessary. Requirement management ensures that all requirements are collected, processed, adjusted and kept up-to-date during all stages of the design and realization phase. SE proclaims that first requirements have to be analyzed thoroughly before designs are made. de Graaf (2014) explain that less redesigns are necessary to create an appropriate design.

2.2.3.5 Decrease rework

de Graaf (2014) defines rework as work performed during realization which is not appraised beforehand. He defines multiple sources causing rework. First source of rework are additional wishes by the client during realization which are not incorporated in the design. SE stresses upon thoroughly deliberating the design. SE reduces rework by ensuring that all requirements and wishes are collected before the realization phase starts. The objective is to limit the amount of alterations in specifications by doing it "the-first-time-right". Second source of rework are design omissions. When after finalizing the design, omissions in the design are uncovered which often result in discussion about who is responsible for the omission. The architect holds responsible for the design and can therefore be responsible for the omission, but a contractor holds some responsibility to signal omissions early. Altogether, SE reduces by means of feedback processes these types of rework by making the design process as transparent as possible and to increase integration between disciplines to prevent design omissions early.

2.2.3.6 Less failure costs

de Graaf (2014) defines failure costs as costs which originate from unnecessary mistakes and shortcomings. Many of these failure costs occur because of insufficient coordination of the interface between disciplines. For example, there must be some space in concrete constructions for pipes to run through a wall or ceiling. At this interface the discipline construction and installations must work together to attune the concrete construction and the pipes, to ensure proper fit. When this is done incorrectly, failure cost can occur when during construction there the left out space is in the wrong location. Additional measures are necessary which can lead to budget and schedule overrun. Due the iterative nature of the SE process the design solutions are continuously being checked if these solutions still meet the (derived) requirements. The change of failures in a subsequant phase of the project is reduced significantly. These failures especially could cause high failure costs. SE improves coordination and communication between disciplines by integrating in the design phase also parties which are normally only involved in the realization phase. Working with multidisciplinary teams provides the opportunity to share knowledge and learn from each other's expertise. Moreover, these teams can explicitly analyze interfaces and the connected challenges. The decomposition of the system into objects and sub-objects enables the multidisciplinary project team to effectively manage interfaces between the system and its environment as well as between sub-objects of the system. The coherence between requirements, the system, objects and interfaces enables the possibility to effectively connect sub-objects to the appropriate party or people in the multidisciplinary project team. This creates greater flexiblity and adjustment.

2.2.4 Summary Dimension A:

When SE is applied in construction projects some principles must be considered to successfully overcome the barriers for implementing SE and realize the values of SE. The SE way of working is broken down into several measurable elements which altogether for a framework. This framework provides the foundation for effectively measuring the SE performance.

The connection between the values and SE elements is presented in the table below.

Table 3: Connecting SE values with specific SE elements.

#	SE value	SE element achieving the SE value
1	Increased satisfaction of interest	RA, FA, Verification and Validation
2	Less resistance	RA, FA, Verification and Validation
3	Increased transparency	Verification and Validation
4	Less redesign	RA, FA, Requirement loop, Design loop, Design Verification and Design Validation
5	Decrease rework	RA, FA, Feedback processes
6	Less failure costs	RA, FA, Feedback processes

2.3 Dimension B: Project Success indicators

In this paragraph, the Project Success dimension of the research framework is broken down into measurable elements. First the definition of project success is explained. Next, the most common project success indicators are presented. Afterward, project performance is related to these project success indicators. Lastly, the measurable elements of project success are presented.

2.3.1 Project success

There are many factors affecting project success in construction project (Chan et al., 2004). To realize a successful project is to attain the project's goals and objectives (Lavagnon, 2009). In a construction project the common project's goals are accomplishment of technical performance, maintaining schedule and remain within budget (Memon, Rahman, & Azis, 2012; Tabish Syed Zafar & Jha Kumar, 2012). However, this definition of a successful project reflects why there is still no consensus of what a successful construction project is (Jha & Iyer, 2007). This definition does not completely reflects a successful construction project. For example, the objective of the project is to renovate a bridge within a certain schedule and to a certain budget. When during the project additional work is necessary to realize this objective, the project can in the end still to some extent be perceived as successful. However, the budget is overrun and the schedule is not hold because of the additional work. From the client perspective, the project is definitely not successful. Still, from the contractor's perspective can the project be successful, because in general contractors profit from additional work. This example makes perfectly clear why project success is ambiguous and bound to a specific context (Lavagnon, 2009). However, budget and schedule are regarded to be the most important indicators for measuring construction project success (Jha & Iyer, 2007;

Memon et al., 2012). These indicators are commonly referred as the "Iron-triangle" of project success. The objective of this research project is to initiate the relation SE metrics to project success. Therefore, the most basis approach to measuring project success is applied. Hence, the Iron-triangle of project success is introduced.

2.3.1.1 Iron-triangle of project success

According to the "Iron-triangle" of project success, a project is successful when it is delivered within budget and schedule and in accordance with the clients' specifications described in the project contract (Locatelli et al., 2014; McLeod, Doolin, & MacDonell, 2012). These three distinctive project success indicators are commonly used in the construction industry to measure project success (McLeod et al., 2012). On average, worldwide approximately 68 percent of the construction project experience budget overruns and approximately 74 percent of the construction project experience delays (Rivera et al., 2016). On average, only 16 percent of construction projects can achieve the set levels in budget, schedule and conformance to client's specifications (Memon et al., 2012). These results suggest construction project are underperforming in terms of budget, schedule and quality performance. However, the scope of the Iron-triangle becomes more and more criticized as being too limited to fully reflect project success (McLeod et al., 2012). Measuring project success in terms of the Iron-triangle, means that other stakeholders views and objectives are not taken into account to determine if the project was successful (McLeod et al., 2012). It is argued that, for example, client satisfaction cannot be measured in terms of conformance to specification. Such subjective indicators of project success are incorporated in the overall perspective of project success (McLeod et al., 2012).

Owners of public projects are investing in the development of various tender procedures with which the contractor is selected who best able to manage project characteristics, such as budget, schedule, quality or stakeholder satisfaction, that affect the success of construction projects (Cho, Hong, & Hyun, 2009; El-Rayes & Kandil, 2005). An example of such an initiative in the Dutch construction industry is Best Value Procurement (BVP) (Rijt, Hompes, & Santema, 2010). Although, more indicators are incorporated in the overall perspective of project success, budget, schedule and quality still remain the top three mostly used project success indicators to reflect contractor's project performance in new tender procedures such as BPV (Booij, 2013; Horstman & Witteveen, 2013; Rijt et al., 2010).

2.3.1.2 Project performance

Performance-related specifications become more relevant in the Dutch construction industry. Performance-related specifications are used in the BVP methodology and defined as BVP objectives which enable effective selection of contractors (Horstman & Witteveen, 2013; Rijkswaterstaat, 2016; Rijt & Santema, 2012; Yu et al., 2013). The BVP objectives are the value for the stakeholders provided by the projects. The contractor with the best performance on these objectives has the highest changes of successfully delivering the project according to these stakeholders' values (Rijt et al., 2010). Performance-related specification defines the level of key construction quality characteristics desired by stakeholders, or in other words, a certain performance which the contracting firms have to meet to achieve the desired stakeholders' values. The total of stakeholders' values define the project success. A common definition of a successful project is according to Winch (2010, p.207) a project which is delivered below budget, on schedule and conforms to specifications.

Four major indicators identifying performance on construction projects (Rivera et al., 2016):

- Rework – work that was not properly done, and required additional hired labor to correct.
- Cost overrun – the amount of money exceeding the original cost.
- Schedule delay – the amount of time exceeding the end completion date (critical path).

- Customer satisfaction – how satisfied the owner/client was with the delivered service.

This is in accordance with Honour (2013) and Rijt et al. (2010), making budget, scheduling and quality (conformance to specifications) the most common key construction quality characteristics and thus common project success characteristics.

Budget and scheduling are quantifiable project success characteristics and therefore easily measurable (Cho et al., 2009; El-Rayes & Kandil, 2005). The project is either within budget and schedule or over budget or behind schedule. However, for quality this is more challenging. Honour (2013) linked budget, scheduling and technical quality (conformance to specifications) with SE effort. He defined conformance to specification as technical quality. Quality or conformance to specification is not just "ticking all the boxes of every requirement". Like Honour (2013), the characteristic of technical quality is based on stakeholders' subjective views of the technical quality which have to be met. Stakeholders have a certain "stake" in the project, or in other words the project (when realized) provide a certain value to the stakeholder. This value is different for each stakeholder, depending on the stakes of the stakeholders. Elm, Goldenson, Emam, Donatelli, and Neisa (2007) measured SE capability and the effect on project performance in terms of cost performance, schedule performance and scope performance (quality), just for military projects like Honour (2013). However, Honour (2013) and Elm et al. (2007) measured technical performance in terms of acquiring subjective stakeholders' values. This makes it challenging to quantify technical performance. Because of the subjective nature, there can be conflicting prescribed levels of technical quality from the stakeholders' perspective. Therefore, it is not possible to quantifiable measure technical quality in this way.

However, conformance to specifications (quality) is achieved by both the quality of the design process as well as the skill of designers within that process to design a project that is conform the specifications. If we focus less on the design quality in terms of conformance to specifications, but more on the design quality in terms of design process quality we can measure this project success characteristic objectively and in a quantifiable way. This is further explained in the next paragraph. Moreover, the application of SE is of interest in the research project. How SE is applied determines the organization of the design process, hence the design process quality is of interest in this research project.

2.3.2 Project success indicators in Dutch construction industry context

In the table below, the measurable elements regarding dimension B: Project Success Indicators are presented. Although, there are many more different project success indicators. To be able to quantify the relation between extent of SE application and project success only measurable project success indicators can be used. "*Common system success criteria are cost, schedule and technical performance"* (Marchant, 2010, p.4). Budget, Schedule and quality are the three main objective and measurable project success indicators (Jha & Iyer, 2007).

Table 4: Overview of dimension B of the research model.

Dimension B: BVP objectives	
Element #1	Budget
Element #2	Schedule
Element #3	Quality

Element 1 & 2: Budget and Schedule
The elements budget and schedule are measured according to the method of Honour (2013). He expressed budget performance as the factor between Actual Budget and Planned Budget. This is in accordance with Memon et al. (2012), who defined budget overrun as the difference between the actual cost of the project and agreed cost target of the project. The project is over budget

when the factor is greater than one and the project is under budget if the factor is smaller than one.

Schedule performance is measured in terms of the factor between the Actual Schedule and Planned Schedule, according to Honour (2013). This is in accordance with Memon et al. (2012), who defined schedule overrun as late completion of work compared to the planned schedule. Who is responsible for the delay or what circumstances resulted in the delay are not taken into account in calculating the schedule factor. Also for schedule performance, when the factor is greater than one, the project is behind schedule and when the factor is smaller than one, the project is within schedule.

Element 3: Quality, measured in number of RfA's
Quality is an qualitative performance indicator, according to Cho et al. (2009). Wanberg, Harper, Hallowell, and Rajendran (2013) defined general construction quality performance in terms of defects and rework. Olawale and Sun (2010) found one of the top variables causing budget overrun to be additional work. Additional work always require a Request for Adjustment (RfA), because the additional work was not part of the original project contract. RfA's are proposed contractual adjustments after original agreement over the contract (de Graaf, 2014). For example, when during construction unforeseen site conditions require additional requirements then the original set of requirements (which is part of the original contract) have to be adjusted to reflect the new situation. Andi and Minato (2003) mentioned rework, delays, costs overruns and changes as common poor performance caused by defective designs. Poor design process performance is characterized by high level of redesign. A common result of redesigns are Request for Adjustments (RfA's) (de Graaf, 2014).

Such a definition of poor quality performance can be used to define the design process quality characteristic of project success. By using this definition it becomes possible to measure design process quality objectively and in quantifiable way. When the design process quality is high, the total number of RfA's will be limited, because unnecessary rework is reduced and potential additional work is found early and can therefore be solved before an actual RfA is necessary. Although, it is presumed that a contractor perceived RfA's as profitable, in practice it is difficult to actual measure profitability of RfA's. A contractor must also invest resources to perform the RfA's. The objective of this research is to initiate a quantifiable relation between the extent of SE application and project success, therefore if RfA's are profitable or not is left out of the scope.

2.4 Integrated theoretical framework

When SE is properly applied it is perceived to prevent budget and schedule overrun while also delivering higher quality systems (BAM, 2008; Bate et al., 1995; Beasley, 2017a; de Graaf, 2014; Defense, 2001; Elliott et al., 2012; Elm et al., 2007; INCOSE, 2006a, 2006b; ISO, 2015; Kapsali, 2011; Locatelli et al., 2014; O'Connell et al., 2013).

2.4.1 Extent of SE application and project success in terms of budget and schedule performance.

Olawale and Sun (2010) performed an extensive questionnaire to find inhibiting factors affecting budget and schedule performance in construction projects. They concluded that the number one factor for both budget and schedule performance is Design changes. Design changes are defined as redesign necessary because designers come up with new or changed insights. Design changes are necessary to develop an optimal design. However, too much design changes can cause budget and schedule overrun (de Graaf, 2014). Unnecessary design changes are mainly caused because missed requirements or new introduced requirements still have to be incorporated in the design (de Graaf, 2014). Moreover, design changes can lead to necessary adjustments to the contract between the client and the contractor. Such adjustments are often affecting the success of the project (de Graaf, 2014). SE is applied to increase control over the design process, perform pre-work not rework and provide less redesign (de Graaf et al., 2016; de Graaf, Vormer, et al., 2017; Honour, 2004; Honour, 2013). SE is applied to perform requirement management, develop design solutions, ensure that the design solutions meet the requirements and to effectively and efficiently integrate design solutions to one overall design which meet all the client's and other stakeholders' requirements by means of verification and validation.

However, like Honour (2013) there will be some optimum for the extent of SE application and budget and schedule performance. Beasley and O'Neil (2016) explained that practitioners must search for the "sweet spot" of SE. This confirms the suggestion for an optimum for the extent of SE application. Beasley and O'Neil (2016) continues by defining three zones for SE application. In the first zone there is underinvestment in SE and thus to realize its' values more complete SE application is necessary. In the second zone there is overinvestment in SE, which suggests that overkill in the extent of SE application is one of the reason for budget and schedule overrun. The third zone is the "sweet spot" or to put it in other words the optimum extent of SE application to add value in the project. Therefore the relation between the extent of SE application and project success in terms of budget and schedule performance can be expressed according to the figure below.

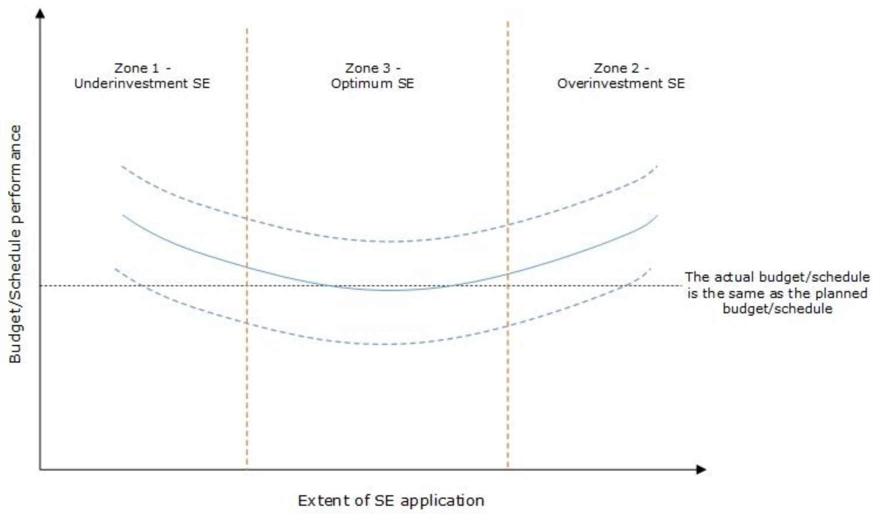

Figure 3: Integrated theoretical framework for extent of SE application and budget and schedule performance.

2.4.2 Extent of SE application and Request for Adjustments.

The relation between the extent of SE application and RfA's is different compared to the relation presented in paragraph 2.4.1. This is mainly because the budget and schedule performance are expressed as a factor between actual budget/schedule and planned budget/schedule. For RfA's, the planned number of RfA's will always be zero. Hence, the factor is always to total number of RfA's in the project.

As de Graaf (2014) and Honour (2013) explain, redesigns can cause contract adjustments. Necessary redesigns are reduced by applying SE and especially requirement management. This suggests that when the extent of SE application increases less redesigns are necessary and thus the change of contract adjustments reduces. This would mean that the total number of RfA's is reduces as well. However, when SE is applied a clear focus is on the analysis of specification documentation to provide a complete list of all the requirements (ProRail et al., 2013). This will provide the contractor with strategic knowledge of possible contract issues/opportunities. These opportunities can result in RfA's during project execution. Such strategic opportunities often provide financial benefit for the contractor. This would suggest that when the extent of SE application increases the change of more RfA's increases as well.

In this research, the application of SE is analyzed from the contractor's perspective. The part of SE in which the actual design is made is often subcontracted to specialized design organizations. The SE application of the contractor does impact redesigns, although indirectly. Hence, it is assumed that the contractor is more likely to invest in acquiring strategic knowledge to gather possible RfA's to make the project more profitable. Therefore the relation between the extent of SE application and the number of RfA's can be expressed according to the figure below.

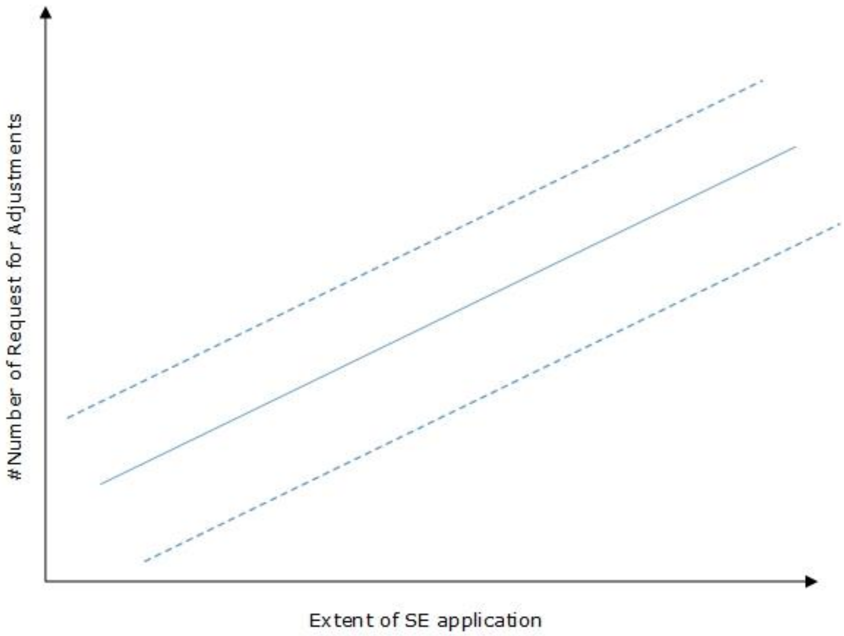

Figure 4: Integrated theoretical framework for extent of SE application and the number of RfA's.

3 Research methodology

3.1 Research design

The research design provides structure and is based on the research background and goals. The analytical framework presents how the research project is supposed to achieve the research goals.

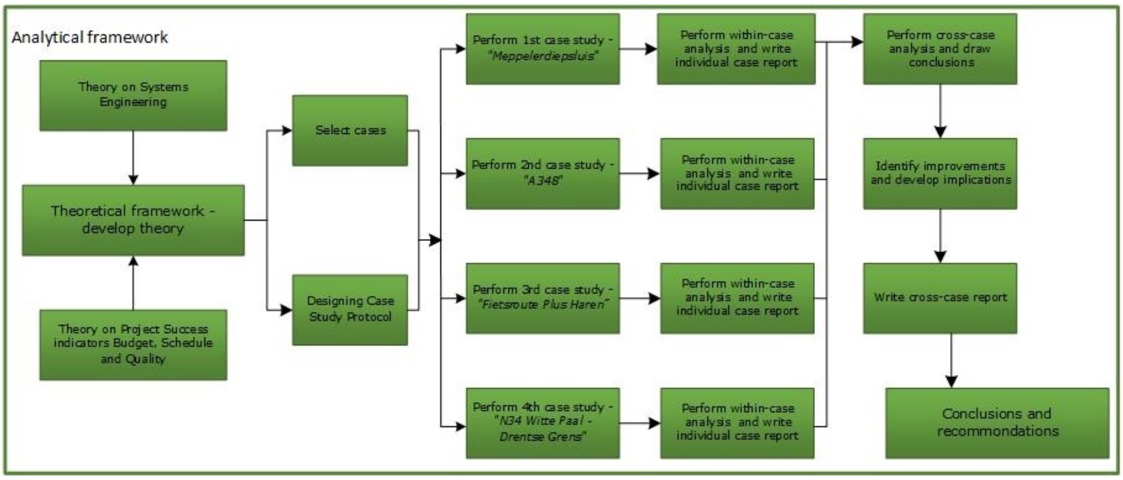

Figure 5: Analytical framework based on multi-case study design by Yin (2014).

3.2 Case study research

The research design is based on the method of Yin (2014). The method of Yin (2014) and why this method is appropriate for this research project is explained in the following paragraphs.

3.2.1 Multi-Case Design

In this research the relation between SE performance and project success indicators budget, schedule and quality is investigated. The relation between SE and project success indicators budget, schedule and quality in the Dutch construction industry is until now not investigated. Honour (2013) initiated an investigation which related SE effort to project success indicators budget and schedule, but his research was limited to Military programs in English-speaking countries. Therefore, the multi-case design is of explorative nature investigating the relation between SE and project success indicators in the context of the Dutch construction industry. This means that there are no propositions structuring the research project, making the rationale in the research design the only way to state purpose (Yin, 2014). The rationale is explained in Chapter 2: Theoretical Framework. When evidence is gather in multiple projects over a full variety of disciplines (Infrastructure and Hydraulic and Concrete Engineering) the evidence is considered to be more compelling (Yin, 2014). The multi-case design enables the researcher to apply literal replication establishing a comprehensive understanding of SE performance and how this performance realizes project success indicators. Literal replication is applied because the amount of appropriate cases is limited to a maximum of four projects. The problem owner does not have many recent projects under UAC-ic in their portfolio.

3.2.2 Unit of analysis

Looking back at the research questions, it is important that the unit of analysis represents the full spectrum of projects realized by the problem owner. Only then a comprehensive overview of SE performance and how this performance ensures realization of project success indicators is established. The selection of case studies is done based upon the one-phase approach by Yin (2014). After an initial search on the website of Reef Infra and "mini-interviews" with employees of Reef Infra connected with the projects, there were only 6 cases appropriate for this research. This selection is done based upon several selection criteria. These selection criteria are based upon the literature study and previous research.

Table 5: Selection criteria for selecting cases.

	Selection criteria candidate cases	Reason
1.	In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.	Scope
2.	A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.	Comprehensive overview of SE application
3.	The used contract in the project is based upon UAC-ic.	Scope
4.	The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.	Recent SE paradigms applied
5.	The main contractor applied Systems Engineering.	Scope
6.	There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.	Comprehensive overview of SE application

The selected cases

The output of the case study selection and therefore the selected cases are as follows:

1. Meppelerdiepsluis, involved discipline(s): hydraulic and concrete engineering;
2. A348, involved discipline(s): concrete engineering;
3. Fietsroute Plus Haren, involved discipline(s): infrastructure;
4. N34 Witte Paal- Duitse Grens, involved discipline(s): infrastructure;

The description of the selected cases and the rationale behind the selection is in appendix I.

3.2.3 Data collection strategy

Important is that all the case studies are mutual comparable to be able to combine findings of the within-case and cross-case analyses. This is ensured by applying the same case study protocol in each of the cases. The case study protocol is in appendix II. Yin (2014) defined four principles of data collection. These principles are applied in this research to ensure proper collection and analysis of data.

Use multiple sources of evidence

Many sources of evidence making case study findings or conclusions likely to be more convincing and accurate. Using multiple sources of evidence enables triangulation. First the document analysis is performed to gather the SE metrics and project success metrics. After the document analysis unstructured interviews are conducted to gather missing info and validate the findings in the document analysis. The sources of evidence are divided into two categories of data sources:

1. Data sources for document analysis;
2. Data sources for unstructured interviews.

Table 6 summarizes the data sources for document analysis. The most important document data sources are the Offering documentation, Project Management Plan and Verification and Validation Plan and Report. These documentation will provide the necessary information for the analysis of the SE application and project success.

Table 6: Data sources for document analysis.

Codering	***Document list***	***Describtion***
D.PI-1	Offering Documentation	Project information: General
D.PI-2	Specification Documentation both Requirements (Vraagspecificatie I) and Process (Vraagspecificatie II)	Project information: Requirements SE
D.PI-3	Project Management Plan	Project information: Project organization
D.PI-4	Design Plan	Project information: Design process organization
D.PI-5	Engineering Plan	Project information: Technical process organization
S.SE-1	Requirement Analysis	Systems Engineering: Initiation SE process
S.SE-2	SBS	Systems Engineering: System decomposition
S.SE-3	WBS	Systems Engineering: System decomposition
D.SE-1	Verification & Validation Plan	Systems Engineering: Verification and Validation process organization
D.SE-2	Verification & Validation Report	Systems Engineering: Verification and Validation results
D.PI-6	Delivery dossier	Project information: Project result
D.PI-7	Design Nota	Project information: Design process development
D.PI-8	Overall Schedule	Project information: Project development
D.PI-9	Installment payment documentation (Termijnstaat)	Project information: Project development

Table 7 summarizes the data sources for the unstructured interview. The interview protocol is explained in more detail in the case study protocol in Appendix II.

Table 7: Data sources for unstructured interview.

Project	**Interviewee**	**Role**
Meppelerdiepsluis	Niek van Bentheim Erwin Nijmeijer	Projectleader Technical manager
A348	Peter Blom Koen Naafs	Process manager Process coordinator
Fietsroute Plus Haren	Martin Meijer Bert Lankheet	Technical manager Process coordinator
N34	Peter Blom Sander Kamphuis Gerben Vossebelt	Process manager Process coordinator Technical manager

Yin (2014) describes four types of triangulation: data triangulation, investigator triangulation, theory triangulation and methodological triangulation. Data and methodological triangulation is achieved by using document analysis and conducting unstructured interviews as two main sources of evidence. Investigator triangulation is achieved by discussing the case study protocol, data and results with senior researchers. Theory triangulation is achieved by applying pattern-matching which compares theoretical patterns with empirical patterns.

Create a case study database
The data is put in a large Excel file. This Excel file is developed as a measurement tool, but it also functions as a database of all the collected data in this research. For each case study the collected documentation is put in the same folder as the case study report. Hence, a cast study database is created.

Maintain chain of evidence
By defining a case study protocol, the chain of evidence is maintained. The case study protocol ensures that in every case study data is collected and analyzed in the same way and in such a way that an external observer is able to follow derivation of any evidence. This also enables the researcher to perform cross-case analysis. Moreover, validity and reliability of the case study findings is increased.

Exercise care when using data from electronic sources
The case study protocol also ensures care when using data from electronic sources. The protocol describes the scope and boundaries of the case studies. The scope and boundaries limit the researcher to a demarcated area of theories. This helps structures the theoretical framework and guides the research in establishing logic in linking theoretical with empirical findings.

3.2.4 Data analysis strategy

Within-case analysis
After collecting the SE metrics and project success indicators metrics, the within case analysis is performed. In this analysis the extent of application for every SE task are compared mutual to see if there are differences or similarities in the extent of application of SE tasks. The objective of this analysis is to determine if the contracting firm is able to better implement specific SE tasks. The differences in the extent of application between SE tasks will provide critical information for the contracting firm. With this information, the contracting firm can specifically target underperforming SE tasks to overall improve their SE application. Moreover, regarding the project success metrics the within-case analysis provide insight in the project specific success in terms of budget, schedule and quality performance. The within-case analysis enables the opportunity to fulfill the goal within the research.

Cross-case analysis
After the extent of the SE application and project success indicators in every case is clear these metrics can be mutually compared. This is done in a cross case analysis by creating three graphs in which SE performance of the cases is set out against project success indicators performance budget, schedule and quality in terms of Request for Adjustments (RfA's).

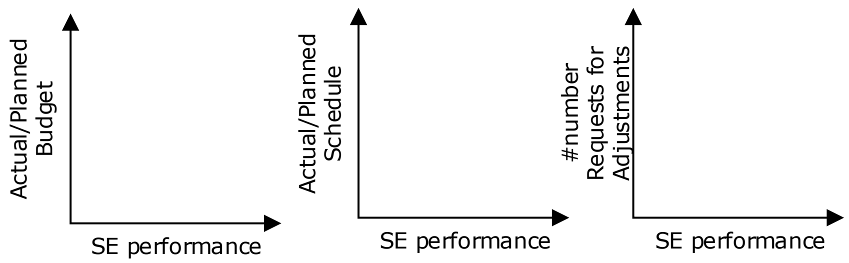

Figure 6: Research output graphs.

By comparing case results in this way possible qualitative relations between SE performance and project success indicators can be derived. Based on the theoretical patterns, the graphs must show a relation which shows a higher SE performance leads to higher performance in project success indicators up until a certain optimum. These indicators are converted to factors to enable cross case comparison. For example, a higher performance in the project success indicator budget shows that the contracting firm was able to realize the project according to the planned budget. Hence, a budget factor close or below 1.0 shows high performance in the related project success indicator budget. If this is the case and the corresponding case(s) also has a relative high SE performance the theoretical patterns can be confirmed too some extend, because these findings are qualitative. The findings can pinpoint to interesting relations which might be of interest to investigate in a future quantitative research.

The cross-case analysis is done to understand the possible relations between the SE metrics and project success indicators metrics and to clarify and utilize the link between SE metrics and project success indicators metrics. The fulfillment for each SE task and project success indicators in every project is compared and possible patterns are appointed. In the cross-case analysis certain links in specific cases are analysis by verification in other case studies. Lastly, by clarifying the links between SE metrics and project success and measuring the fulfillment of both, it might become possible to be able to suggest improvements in the SE application and the achievement of project success indicators. This can provide an opportunity to establish patterns to determine what extent of SE application is necessary to realize a project successfully. The cross-case analysis enables the opportunity to fulfill the goal of the research.

3.3 Validity and reliability

In this research the application of SE is observed after the actual application of it in the projects. The outcomes of the research are therefore inferences were especially the completeness of explanations and all possibilities is of concern. However, internal validity is less a concern in this research as the research is of iterative nature. The internal validity is increased by using the pattern matching method by Yin (2014). The external validity is concerned with the generalization of the research findings (Yin, 2014). The form of original research question hinders the preference for seeking generalizations. In this research the application of SE at one main contracting firm is analyzed and improvement implementations for this main contracting firm are suggested. Therefore, the preference of this study is not to seek for generalizations, but to complement previous research to enable generalizations and to initiate research concerned with linking project the extent of SE application to project success indicators. To some extend the external validity is increased by comparing the results of both the within-case analyses as well as the cross-case analysis (Yin, 2014). The validity is also increased by gathering feedback on findings from expert practitioners, such as Reef Infra employees and academic experts.

Reliability is concerned with arriving at the same findings and conclusions when applying the described research procedure to minimize errors and biases in the research (Yin, 2014). To increase reliability a chain of evidence is maintained. The reliability of this research is increased by applying a multi-case study design and setting up a case study protocol and apply the same protocol at each case study. This also enables the option of cross-case analysis as results are acquired in the same way (Yin, 2014). In the case study protocol the research steps are operationalized to enable other investigators to replicate these research steps and come to the same findings and conclusions.

3.4 Introducing measurement tool

The measurement tool is introduced in this paragraph. First, how the extent of SE application is quantified in the measurement tool is explained. Second, how the budget and schedule factors are calculated is presented next. Third and final, an overview of the output score matrix of the SE measurement tool is presented.

3.4.1 Quantification of extent of SE application

The measurement tool to analyze the cases and the SE application is subdivided into three parts, according to de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017). The first part consists of the SE process framework. This framework is used to quantify the extent of the SE process of the contracting firm. Based on the framework, an extensive list of questions about the extent of application of SE tasks is developed. The elements of SE (presented in paragraph §2.2.2) provide the foundation for these questions. The questions are of such detail that these can be answered with "Yes" and "No", were "Yes" means that this specific tasks is completely applied, "No" means that this specific tasks is not applied at all and "Yes/No" means that the specific SE tasks is partially applied. Points are allocated to the answer of the question to quantify the extent. The allocation of points is as followed:

- Yes = 5 points
- No = 0 points
- Yes/No = 2.5 points.

After points are allocated, the second part of measuring SE application is performed. This part consists of a method to determine fulfillment of the SE elements. The maximum score of each element is 100% meaning 100% of the SE process framework is applied. The fulfillment is calculated as followed:

SE tasks fulfillment = sum of all scores of all questions / maximum number of points.

To clear this up, an example is presented in Table 8.

Table 8: Example calculation SE tasks fulfillment.

Question regarding SE element "Functional Analysis"	Answer	Score
Is the output of the FA the FBS?	Yes	5
Is the output of the FA the SBS?	No	0
Do the description of a function consist of a noun and verb?	Yes/No	2.5
	Number of questions	3
	Total points achieved	5+0+2.5 = 7.5
	Maximum points to achieve	3 x 5 = 15
	Fulfillment percentage	(7.5/15) x 100% = 50%

3.4.2 Quantification of Project success indicators.

To quantify the project success indicators, additional documentation is analyzed. An overview of the documentation is presented in Table 6.

To quantify budget and schedule performance the planned budget and schedule is compared with the actual budget and schedule after delivery of the project. To determine the actual budget and schedule, the final installment payment and final starting and delivery date are derived from the listed documentation. To determine the planned budget and schedule, the offered price and offered starting and delivery date are derived from the listed documentation. The factors for budget and schedule performance are calculated according to the following calculations:

Budget Performance = Actual budget spent / Planned budget

Schedule Performance = Actual schedule / Planned schedule

To clear this up, an example is presented in Table 9.

Table 9: Example calculation Schedule performance.

Planned Schedule	Actual Schedule	Schedule performance factor
250 working days	281 working days	281/250 = 1.12, hence there is a 12% delay.

After clarifying the two quantification methods of the extent of SE application and project success, the output of the measurement tool can be presented in the next paragraph.

3.4.3 Output of the measurement tool

For each case project, a matrix was made to summarize the scores of each SE element. The matrixes are used for the within-case and cross-case analyses. An overview of the overall score matrix is presented below.

Systems Engineering taks	Project name [%] # # # # #	Avarage SE-taks	Discipline avarage [%]	#
Input Requirement Analysis (RBS) Functional Analysis (FBS) Work Breakdown Structure (WBS) Solution Synthesis Output				
Requirement loop Design loop Verificition Design Phase Valdiation Design Phase Verification Realization Phase Validation Realization Phase				
V-model				
Overall SE score				
BVP Objective	**Project name [%] # # # # #**	**Avarage BVP objective**	**Discipline avarage [%]**	**#**
Actual/Planned Budget Actual/Planned Schedule Design Process Quality				
Overall BVP Objective score				

Figure 7: The overall score matrix output of the measurement tool.

4 Results

4.1 Introduction

In this chapter the results of the case studies are presented. The measurement tool, developed by de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017), was adjusted to enable the analysis of the SE process of a contracting firm in the Dutch civil engineering industry. After performing the extensive documentation analysis and a number of interviews, all the questions in the tool were answered and fulfillment of SE tasks application was determined. Project success in terms of budget, schedule and quality was determined as well and the metrics were put in the measurement tool. First, an overview of the results of the measurement tool is presented. Second, the within-case results are presented for every case. Third and final, the cross-case results are presented.

4.2 Overview results

Table 10: Overview results of the case studies.

Project characteristics	**Case 1: MDS-WA**	**Case 2: A348-BE**	**Case 3: FPH-WE**	**Case 4: N34-WE**
Budget Factor	1.85	1.19	1.17	N.a.
Schedule Factor	1.46	1.42/1.0	1.03	N.a.
Number of RfA's	45	26	16	N.a.
Contract type	UAV-ic	UAV-ic	UAV-ic	UAV-ic
--> EMAT = 1, BVP = 2	1	1	2	1
Main Discipline	Hydraulic engineering	Concrete engineering	Infrastructure	Infrastructure
Client	Rijkswaterstaat	Provincie Gelderland	Gemeente Haren	Provincie Overijssel
SE-tasks	**Case 1: MDS-WA**	**Case 2: A348-BE**	**Case 3: FPH-WE**	**Case 4: N34-WE**
Input	54%	71%	71%	54%
Requirement Analysis (RA)	77%	85%	81%	87%
Functional Analysis (RA)	67%	35%	48%	65%
Solution Synthesis (SS)	50%	50%	67%	67%
Output	75%	75%	75%	75%
Requirement Loop (RL)	50%	50%	25%	50%
Design Loop (DL)	45%	30%	30%	65%

Verification Design phase (Ver. Des.p)	82%	82%	77%	77%
Validation Design phase (Val. Des.p)	10%	60%	50%	50%
Verification Realization phase (Ver. Rea.p)	67%	67%	61%	72%
Validation Realization phase (Val. Rea.p)	17%	33%	8%	17%
V-model	83%	67%	83%	100%
Work-Breakdown-Structure (WBS)	67%	46%	46%	85%
Overall SE score	57%	58%	56%	66%
Base process (RA, FA, WBS and SS)	66%	54%	60%	76%
Feedback process (RL, DL, Ver. Des.p, Val. Des.p, Ver. Rea.p, Val. Rea.p)	45%	54%	42%	55%
Structuring/Support (V-model, Input, Output)	71%	71%	77%	76%

4.3 Results

In this paragraph, the results of both the SE and Project success indicator measurements are presented. A more in-depth analysis of the results is presented in chapter 5: Discussion. First the case specific results are presented. Afterwards, the cross-case results are presented and the level of SE application and project success are determined.

4.3.1 Within-case results: Case specific results

4.3.1.1 Case 1: Meppelerdiepsluis

The case specific results of Case 1: Meppelerdiepsluis are presented in Table 10. The extent of the base process (66%) and support process (71%) is significantly higher than the extent of the feedback process (45%). This would suggest that in this project Reef Infra struggled with SE specific tasks regarding verification, validation and the different feedback loops. However, the RA (77%) and Verification Design phase (82%) score high fulfillment. The FA (67%), WBS (67%) and Verification Realization phase (67%) score significantly lower compared to the RA (77%) and Verification Design phase (82%), but still the scores remain above average (57%). Hence, specific SE tasks in the Feedback process significantly lack fulfillment. The Design Loop (45%), Validation Design phase (10%), and Validation Realization phase (17%) score really low on fulfillment compared to the average score (57%).

Looking at the successfulness of the project, the results suggest that the project was a disaster. The budget factor is 1.85, which means the actual budget was 85% larger than the planned budget. The schedule factor is 1.46, which means the actual schedule was 46% larger than the planned schedule. The total number of Request for Adjustments is 45.

4.3.1.2 Case 2: A348

The case specific results of Case 2: A348 are presented in Table 10. The extent of the support process (71%) is significantly higher than the extent of the base process (54%) and the feedback process (54%). This would suggest that in this project Reef Infra struggled in general with SE tasks but there were no specific tasks which significantly lacked fulfilment. The RA (85%) and Verification Design phase (82%) score high fulfillment. The Validation Design phase (60%) and Verification Realization phase (67%) score significantly lower compared to the RA (85%) and Verification Design phase (82%), but still the scores remain above average (58%). The Functional analysis (35%), Design loop (30%), and Validation Realization phase (33%) score low on fulfillment compared to the average score (58%).

Looking at the successfulness of the project, the results suggest that the project was to some extent successful. The budget factor is 1.19, which means the actual budget was 19% larger than the planned budget. The schedule factor is 1.0, which means there were no delays in the project. The total number of Request for Adjustments is 26. However, when Reef Infra was the winner of the initial tender procedure, the schedule factor would be 1.42, which means the actual schedule was 42% larger than the planned schedule.

4.3.1.3 Case 3: Fietsroute Plus Haren

The case specific results of Case 2: Fietsroute Plus Haren are presented in Table 10. The extent of the base process (60%) and support process (76%) is significantly higher than the extent of the feedback process (42%). This would suggest that in this project Reef Infra struggled with SE specific tasks regarding verification, validation and the different feedback loops. However, the RA (81%) and Verification Design phase (77%) score high fulfillment. The Solution Synthesis (67%) and Verification Realization phase (61%) score significantly lower compared to the RA (81%) and

Verification Design phase (77%), but still the scores remain above average (56%). Hence, specific SE tasks in the Feedback process significantly lack fulfillment. The Requirement Loop (25%), Design Loop (30%) and Validation Realization phase (8%) score really low on fulfillment compared to the average score (56%). The FA (48%), Validation Design Phase (50%) and WBS (46%) score about or just below the average score (56%).

Looking at the successfulness of the project, the results suggest that the project was to some extent successful. The budget factor is 1.17, which means the actual budget was 17% larger than the planned budget. The schedule factor is 1.03, which means the actual schedule was 3% larger than the planned schedule. The total number of Request for Adjustments is 16.

4.3.1.4 Case 4: N34

The case specific results of Case 4: N34 are presented in Table 10. The extent of the base process (76%) and support process (76%) is significantly higher than the extent of the feedback process (55%). Although, in all of the process more than 50% of SE specific tasks are applied. This would suggest that in this project Reef Infra only struggled to some extent with SE specific tasks regarding verification, validation and the different feedback loops. However, the RA (87%), Verification Design phase (77%), Verification Realization phase (72%) and WBS (85%) score high fulfillment. The Solution Synthesis (67%) scores significantly lower compared to the RA (87%), Verification Design phase (77%) and WBS (85%), but still the scores remain above average (66%). Hence, some specific SE tasks remain more of a struggle for Reef Infra. The Requirement loop (50%), Validation Design phase (50%), and Validation Realization phase (17%) score low on fulfillment compared to the average score (66%).

The project is yet to be delivered. The fulfillment of SE tasks could be determined because one third of the project was already delivered. The SE application up until that point would reflect the SE application for the rest of the project. However, two third of the project is yet to be delivered. Hence, the successfulness of the project cannot be determined.

4.3.2 Cross-case results: Level of SE application

The level of SE application include the Overall SE score, Base, Feedback and Support processes scores and SE-task specific scores.

4.3.2.1 Scores: Overall SE

The lowest Overall SE score is 56% whilst the highest Overall SE score is 66%. This means on average over the four cases approximately 59% of the SE process is applied in the projects. This means there is room for improvement. However, it seems that project characteristics complexity, presence of a demanding experienced client, available budget and available project duration impact the SE application of a contracting firm. Firstly, when project complexity increases more of the SE process is applied in the projects. The case with the lowest SE application is also the most straightforward project compared to the other projects in the other cases. Secondly, when a demanding client is present more of the SE process is applied in the projects. Case 1 had a demanding experienced client compared to case 2. The client in Case three and four was initially very demanding, but lacked experience compared to case 1. Third, if the available budget increases more of the SE process is applied in the projects. The case with the highest SE application is also the project with the highest budget compared to the other projects in the other cases. Fourth and final, when project duration increases more of the SE process is applied in the projects of the cases. The project duration, even leaving schedule delay out of the comparison, in case 1 and case 4 is larger compared to case 2 and 3.

4.3.2.2 *Scores: Base process, Feedback process and Structuring/Support process*

On average the Base process score is 64%, the Feedback process score is 49% and the Support process score is 74%. The Base process and the Support process scores are higher than the Overall SE score. The Feedback process score is lower than the Overall SE score. The Base process consist of the Requirement analysis, Functional Analysis, Work-Breakdown-Structure and Solution Synthesis. The Feedback process consist of the Requirement Loop, Design Loop and Verification and Validation in the design and realization phase. The Support process consist of structuring SE tasks such as the V-model, Input and Output. Reef Infra scores better on SE tasks which are part of the Base and Support process then on SE tasks which are part of the Feedback process. The Base process mainly consist of the first three major SE tasks (RA, FA and WBS). Output of these analysis provides Reef Infra with the information which the system has to meet to be accepted by the client. Because this information is vital, Reef Infra puts a lot of effort in these analysis. The Feedback process is more challenging for Reef Infra. Output of the Base process have to be connected to enable the development of design solutions, verification and validation procedures. For example, to verify and validate if the finished activity (WBS) has realized an object (FA) that fulfills its' functions (FA) and its' requirements (RA) connections have to be made.

4.3.2.3 *Scores: SE-task specific*

Element 1: Requirement analysis (RA)
In every project the Requirement analysis was performed in Relatics, which is an information software program. The output of the analysis was always the RBS. The requirements were structured and elaborated in detail. The RBS was in every case linked to the SBS, but not with the WBS and/or the FBS (case 3 and case 4). The level of detail of requirements was not allocated in every project. Moreover, in every project the Customer Requirements Specifications were not made.

Element 2: Functional analysis (FA)
In every project objects are assessed and structured (Case 1 to 4) and in some projects objects were elaborated in detail by describing object specifications (Case 1). In few projects were also functions assessed and structured (Case 1 and 3). Although the functions were not properly used in all of these project. The FBS was properly linked to the RBS and/or SBS. The SBS was always the output of the FA. However, the FBS was only in two of the four projects the output of the FA.

Element 3: Solution Synthesis
The design is subcontracted to another firm in every case. Therefore this SE-tasks is scored low from a contracting firm perspective. However, every design decision in which the contracting firm is incorporated can be related to requirements or other specifications. However, in every project was the FA not reconsidered based on the Solution Synthesis because the FBS was not linked to the SBS.

Element 4: Requirement loop
In almost every projects was the RA not reconsidered based on the FA. Although it is presumed that in every project this is in practice not the case and the RA is at least partially reconsidered based on the FA, but because no evidence can be gathered to prove this presumption it is assumed that the RA was not reconsidered based on the FA.

Element 5: Design loop
The design loop considers requirements, functions and objects. In three of the four projects the FBS is made but not properly used. Therefore functions are not adjusted in the design loop. Requirements and objects were adjusted in the design loop. However, in every case there were no records of design decisions behind these adjustments.

Element 6: Verification Design phase

A verification plan was used in every project. Every project contained a verification report as a result of the verification phase. In all four projects the design was altered based on verification results when the design did not meet the requirements. In 1 project there was a clear difference between the Verification and Validation plan design phase and Verification and Validation plan realization phase (case 3). This was however constrained by the client.

Element 7: Validation Design phase

In some projects was the validation process incorporated in the verification process. There was no specific validation plan and validation report in every project. In two projects (case 2 and 3) validation was performed by the project team. The project team discussed with the client the Specification documents provided by the client. This ensured agreement over design principles, which supported design decisions. Moreover, in one case (case 3) the preliminary design plans were discussed as well with other stakeholders (then the client).

Element 8: Verification Realization phase

In every project verification during the realization phase consisted of inspections of parts of the work. The result was always a verification report with evidence of verification of requirements. In one case (case 3), some of the negative verification results were not properly communicated and incorporated in the report. At delivery, these became discussion points.

Element 9: Validation Realization phase

There is no specific validation performed in the realization phase in all projects. Only in case 2 there was some type of validation in the realization phase. The contractor performed a "pre-check" of the project with the client just before the project was supposed to be delivered to the client. This was done to find possible delivery discussion points to be able to solve these before the actual delivery was done.

Element 10: WBS

In every project activities were structured in the WBS in Relatics. Description of activities was almost in all projects not described in Relatics (Case 2 and 3). In only one project was verification executed based on solely activities and not objects as well as activities (Case 2).

4.3.3 Cross-case analysis: Project success

The results from the case studies are presented for each individual project success indicator (Table 11). For three out of the four case studies the factors Budget and Schedule and number of Request for Adjustments are gathered. Case 4 is yet to be delivered. Therefore, the actual Budget and Schedule cannot be derived from the project documentation. This means the factors cannot be calculated and the total amount of RfA's can only be determined after final delivery.

Table 11: Overview of the project success indicator results.

Project success indicators	**Case 1: MDS**	**Case 2: A348**	**Case 3: FPH**
Factor Budget	1.85	1.19	1.17
Factor Schedule	1.46	1.0/1.42	1.03
# Request for Adjustments (RfA)	45	26	16

4.3.3.1 Project success indicator: Budget

Looking at the table above, the average Budget factor is 1.40. Over the three cases the actual budget exceeds the planned budget by 40%. However, it must be mentioned that case 1 is an exception. During the project one of the major subcontractors went bankrupt. This caused a lot of additional costs for handing over the work to another subcontractor. What also caused many additional costs was the low initial offered bidding-price. The project was part of a larger maintenance program of Rijkswaterstaat. This project would be a good reference for future maintenance projects for Rijkswaterstaat. During tender procedure, Reef Infra/Strukton Civiel chose to put in competitive bid to ensure they would come out as winner. There was little to no margin in the initial budget. Hence, the chance of exceeding initial budget was high. When the Budget Factor of case 1 is left out, on average the actual budget exceeds the planned budget by approximately 20%. Hence, over the three projects the number of RfA's is on average 29. The RfA's account for an average of 20% additional costs compared to the planned budget.

4.3.3.2 Project success indicator: Schedule

The average Schedule factor is 1.16. Over the three cases the actual schedule exceeds the planned schedule by 16%. However, it must be mentioned that case 2 is an exception. Reef Infra wasn't the initial winner of the tender. After Reef Infra was eventually appointed as the winner, Reef Infra took time to redo their initial offer. New risks were incorporated in the budget and schedule. In this case there are two planned schedules, the schedule made for tender and version 2.0 made after eventually receiving the project. Reef Infra realized the project according to schedule version 2.0. This would mean the Schedule Factor would be approximately 1.0. However, in this schedule more risks were incorporated and the schedule was not made under competition which means less pressure is there to deliver the project in the shortest amount of time possible. When Reef Infra was the initial winner they maybe would have delivered the project in the same time as accounted for in schedule version 2.0. The Schedule Factor would then be 1.42. If the higher factor is used than the average Schedule factor would be 1.30. Over the three cases the actual schedule would then exceed the planned schedule by 30%. Hence, over the three projects the number of RfA's is on average 29.This would mean that the RfA's account for an average of 30% delay compared to the planned schedule.

5 Discussion

5.1 Introduction

In this paragraph we discuss the challenges in the SE process which were encountered in the case studies. The challenges are divided into unclear SE procedures, SE skill and knowledge and Client dependency. Afterwards, the challenges are linked (if possible) to the results of the project success indicators.

5.2 Data analysis

The challenges encountered in the SE process are subdivided into Unclear SE procedures, SE skill and knowledge and client dependency. Afterwards, the SE tasks fulfillment are linked to the project success indicator results. Keep in mind that findings are limited and the discussion of SE results are based on four cases and the discussion of Project success in relation to SE results are based on three cases.

5.2.1 Unclear SE procedures

In all of the cases, evidence can be found which suggests the SE procedures are unclear. SE procedures seems outdated, many steps in the procedures are not performed and there is lack of commitment to the set SE strategy. The results suggest that unclear procedures cause over and/or underinvestment in the SE process. Establishing clear SE procedures is very important, according to Elliott et al. (2012). SE activities overlap multiple existing disciplines, making agreement over clear SE procedures crucial for high SE performance.

5.2.1.1 Unclear and outdated procedures

In every project the Reef Infra Handbook SE is applicable. The handbook SE describes how SE-tasks have to be performed in the projects of Reef Infra. The handbook is well-structured and all employees know in general its contents. In every case, the SE process applied in practices represents resemblance to the SE process described in the handbook. The SBS and WBS are well structured and verification during realization phase is always done based on inspection plans. However, many of the output documents, part of the handbook and therefore of work procedures, are not generated in practices or the standardized formats are not used or altered for project specific reasons. For example, in the Handbook SE the product verification plan is subdivided into an Overall verification plan Product requirements and Overall verification plan Process requirements. However, in practice, in all cases, there is just one overall verification plan, which also has additional components compared to the format described in the handbook. There are more SE task related products which are in practice different than the standardized formats in the Handbook SE.

In official project documentation, such as the Project Management plan, the practical organization of the SE process is described in the overall "UAV-ic Realization management process". However, only generic SE-tasks ("Organize SE", "Validate requirements", Execute SE, etc.) are mentioned in this process. For specification of the SE-tasks the client is referred to the Handbook SE. However, when most of the standardized output documents described in the SE handbook are not used in practices or other formats are applied, then the SE process described in the overall UAV-ic Realization management process must be outdated and not attuned to current day best practices.

Although the SE process described in the handbook is well structure, the SE process is incomplete and over the four cases, the SE application lacks consistency. This is confirmed by van Ruijven (2013), who explains the implementation of SE lacks integrality and consistency in major Dutch infrastructure projects. The following SE-specific tasks are not incorporated in the SE handbook:

- Functional Analysis;
- Requirement loop;
- Validation Design phase;
- Validation Realization phase.

One major concern, specific validation activities are not described in work procedures of Reef Infra. Marchant (2010) confirms that specific Validation is challenging. Validation is sometimes disguised as verification. This is also the case in the UAV-ic Realization management process in which validation is mentioned as part of the SE process. In all the Verification and Validation plans and Verification and Validation reports, the validation process is not specifically described but presented as it is part of the verification process. This means that Reef Infra does not have a specific validation process. The Handbook SE does not describe how validation must be performed. In two out of the three cases they performed some validation in the design phase by discussing Specification documentation with the client. In one case Reef Infra also performed some validation in the realization phase by conducting a pre-check of the work with the client right before the project is supposed to be delivered to the client. However, these validation activities are not part of a pre-defined validation process. According to Marchant (2010, p.2), disciplined validation is a prerequisite for achieving project success in terms of budget, schedule and quality.

Validation covers all other SE activities (Marchant, 2010). Hence, practitioners on the project level are under the impression that validation does not consist of specific tasks. Disciplined documentation, accurate allocation of requirements, functions, objects and design solutions and logical structure in the RBS, FBS and SBS are all achieved by the validation process. Validation improves documentation discipline because in validation there is always interaction with the client or other stakeholders, which almost always consist of official documentation (i.e. Verification and Validation plan). Validation improves accurate allocation of requirements, functions, objects and design solutions because specification documentation and design principles are discussed with the client. Furthermore, by discussing such documentation, an in-depth understanding of the project is acquired which ensures choosing proper structuring of requirements, functions, objects and design solutions. Therefore, the validation process does has specific tasks. Hence, these must be described as such in the SE handbook and UAV-ic realization process of Reef Infra.

Overall, the handbook and the UAV-ic realization management process seem outdated and there is no clear understanding and description of all SE tasks. Participants of SE know the general contents of the procedures described in the SE handbook, but do not work according to these procedures. Instead they rely on their own knowledge and experience. As a result, generic SE tasks are performed differently with different output generated in projects of Reef Infra.

5.2.1.2 SE Relatics process

A second explanation of why SE tasks are not fully applied is the SE process being structured in Relatics. In every project, Relatics is used to structure and automate the SE process. Relatics is the main information management tool in the Dutch construction industry to structure and automate the SE process (van Ruijven, 2013). However looking at every case, different Relatics Templates are used. van Ruijven (2013) confirms inconsistency in the use of Information Models in major Dutch infrastructure projects. Overall the SE templates used in the cases have 13 different possible components.

Table 12: Possible Relatics Template components and how they are used.

Template component	#number of times in template	Actually and properly used in the project [yes (# times) / no (# times)]
Requirement analysis	3	Yes (3)
Functional analysis	3	Yes (1) and No (2)
FBS	2	Yes (1) and No (1)

SBS	3	Yes (2) and No (1)
OBS	3	Yes (3)
WBS	3	Yes (1) and No (2)
Verification	3	Yes (3)
Interface management	3	No (3)
Risk management	3	Yes (1) and No (2)
Document management	3	Yes (2) and No (1)
Request for adjustments	3	Yes (2) and No (1)
Stakeholders	3	Yes (1) and No (2)
Payment Installments	2	No (2)

Looking at the table above we see that the Relatics template is very different in each project. The procedures described in the SE handbook do not correspond with the SE templates used in the cases. This causes practitioners to let aside the procedures in the SE handbook and continue to apply their own experience and knowledge. This hampers Reef Infra to develop their SE process and standardize the Relatics SE process (van Ruijven, 2013). Technical applications must be up-to-date to ensure construction project success (Memon et al., 2012). Furthermore when analyzing the Relatics template, a lot of the components in the templates are left blank. These unused additional options in the template create chaos and uncertainty. Especially in one case, some of the components are left blank even when these are mentioned in the Project Management Plan and are therefore part the project specific SE process. Hence, the structure of the SE process in Relatics must correspond with the established SE procedures and the project characteristics (Beasley, 2017b; Beasley & O'Neil, 2016). If not, the extensive amount of opportunities provided in Relatics only hampers the SE process.

5.2.1.3 *Over and/or under investment*

Another explanation why SE-tasks were not applied completely is over and/or under investment in the SE process. In case 1, Reef Infra overinvested in the SE process for multiple reasons. First, the project was deemed complex by Reef Infra. All of their disciplines had to work together to successfully realize the project. Secondly, this was the first major project for Reef Infra in which they applied SE. They invested heavily to ensure successfulness of their SE process. However, due to overinvestment there was too much project information gathered which made them lose the overview over the SE process. Marchant (2010), confirmed this as a major failure criteria affecting budget, schedule and quality performance of a project. Combined with inexperience, this caused that some tools of SE where not properly and fully applied. The SBS and WBS were not continuously adjusted but at some point in the design process these structures were frozen. This was done to ensure overview, however this worked counterproductive and made incorporating temporary objects (temporary location for the bridge to maintain traffic flow) impossible. Lastly, due to inexperience there was no clear integral SE coordination. Some of the project parts were subcontracted to specialized subcontractors. It was sometimes unclear who was responsible for corresponding SE activities. That the SE process lacks integrality is also confirmed as a challenge hampering project success (van Ruijven, 2013). In this case overinvestment of the SE process caused for their own challenges which lead to incomplete SE tasks further on in the SE process and even more pressure on the schedule and budget performance of the project.

In case 3 there was also overinvestment. The project was not complex and of relative small scale. However, the SE process prescribed by the client was intensive. Reef Infra therefore invested a lot in their SE process to meet the client's standards. During realization of the project Reef Infra experienced that the SE process was too intensive for the project. Too much information was gathered in Relatics and for some subcontractors the SE process did not fit well with their own quality management process. At some stage in the project, Reef Infra therefore decreased their SE investment, resulting in stepping away from Relatics therefore decentralizing their SE process and some of the information gathered became redundant. For example, the output of the FA was the FBS but the FBS was not linked to the RBS, SBS and WBS making the FBS redundant.

In case four there was underinvestment in the SE process. Reef Infra promised (in their bid during the tender phase) that the design process was concise. This promise made Reef Infra to meet project deadlines. After final tender, Reef Infra rushed to start their design process. They did so while the client was still starting up their project team organization. The underinvestment in the SE process of Reef Infra had an effect on for example the level of detail of the RBS. Reef Infra chose to maintain a low level of detail to decrease the amount of requirements which had to be verified and validated. This created a lot of tension and discussion between Reef Infra and the client. The client was not convinced by the chosen level of detail and ordered Reef Infra to apply a higher level of detail. Reef Infra did not agree because they were convinced that the chosen level of detail was appropriate for the project complexity. An intervention was necessary to resolve discussions and to ensure agreement over the right way to move forward. In this case, underinvestment in the SE process was hampering project progress because there was not enough foundation for decisions regarding the SE process.

In case two there was also underinvestment in the SE process, but this did not hamper project progress. Reef Infra was able to create enough foundation to convince the client of the appropriateness of the level of investment in the SE process. Underinvestment in the SE process made this project a success, because it kept the SE process simplistic, efficient and effective. Reef Infra did not made Customer Requirements Specifications and did not allocated level of detail to the RBS. Moreover, no Object specifications were made and there was no specific validation process. However, in creating foundation for the underinvestment in SE Reef Infra organized meetings with the client to discuss Specification documentation to reach agreement over design principles. This helped the client in trusting Reef Infra that keeping the SE process simplistic, efficient and effective was appropriate for the complexity of the project.

The case results suggest that deciding on the appropriate extent of SE application is challenging. This is also confirmed by de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017). Marchant (2010) explains that effective SE management considers a trade-off between investment in SE specific tasks and the value delivered in terms of cost, schedule and technical performance. He describes a possible tradeoff as: *"the need for accurate and consistent specifications versus heavy cost of non-essential requirements that constrain the design"* (Marchant, 2010, p.4). This confirms that the extent of SE application follows an optimum. Underinvestment affects project success and overinvestment affects project success. Honour (2013) and Beasley and O'Neil (2016) argue for approach the SE process as a flexible process and not as a rigid set of tools. This approach ensures proper adjustment of the SE process while considering project characteristics. The SE handbook must describe how this decision process must be performed. Approaching SE as a flexible process requires proper training to ensure that the practitioners are able to make the right decisions (Beasley, 2017b; Beasley & O'Neil, 2016). This would reduce the change of over- and underinvestment.

5.2.2 SE skill and knowledge

The second explanation for the extent of SE application is SE skill and knowledge of the practitioners. In all projects, employees were in a learning process. Overall, employees lacked especially skills and knowledge regarding the feedback process SE activities. In particularly, validation was not specifically performed and employees found it challenging to explain what they perceived as validation activities. In every project of Reef Infra, practitioners struggle to determine which activities to perform and the degree of rigor with which to perform them. Beasley and O'Neil (2016) confirms this as a problem being discussed in the SE community. This, for example, results in discussion with the client over the appropriate level of detail in the RA. Also, practitioners just follow the by the clients' prescribed SE process, without determining if this is the proper SE approach for the project characteristics in terms of size, complexity, duration, etc.

The project in case 1 was the first test case for the application of SE. The project was awarded to Reef Infra in 2012. Back then, the SE Handbook was still in development. This suggest the project's SE process was performed while there was no agreement over the general SE procedures of Reef Infra. Hence, in that project practitioners lacked the proper SE skill and knowledge to apply SE tasks to their full extent and the employees were still in a learning process. In case 3, some employees mention that the SE handbook was available but that it was outdated and there was not enough time for proper training in SE. Still, as SE was prescribed in all the projects by the client, the employees had to perform specific SE tasks. This resulted in three cases that the skill and knowledge that the employees of Reef Infra lacked was hired externally. These external organizations brought their own Relatics templates, hence the SE handbook and thus the SE procedures of Reef Infra did not correspond with these Relatics templates. This made employees of Reef Infra very dependent on the skill and knowledge of the external organization. Moreover, employees started focused more on just applying some tools and not on how SE can be used to ensure project success. This dependence on external organizations also hampered sharing of knowledge amongst employees of Reef Infra. In some projects, project specific solutions were generated to overcome certain SE process challenges. For example in one project, Reef Infra had a lot of work outsources to subcontractors. This work had to be inspected, which was performed by the subcontractors themselves according to their own quality management system. This created a number of inspection results all in different formats and presenting different information. Hence, Reef Infra developed a standardize inspection report front page to ensure that the crucial information was communicated quickly. Such project specific solutions were not shared within the entire organization.

That Reef Infra lacks proper skill and knowledge regarding SE seems evident. In literature proper SE skill and knowledge is also mentioned to affect SE application. One of the main barriers for realizing SE value is the common, but wrong, perception of SE that it is merely a combination of tools and processes. Not the well-established tools and process are crucial for realizing the SE values, but the competency of people performing it that is wat realizes the SE value. Systems Thinking, proper problem analysis, well-informed decision-making and working traceable and transparent are crucial in realizing SE value (Beasley & O'Neil, 2016). That proper training is necessary to apply SE to its full extent is also confirmed by Godfrey, Crick, and Huang (2014), de Graaf et al. (2016) and de Graaf, Vormer, et al. (2017). Moreover, to increase knowledge sharing and to increase the realization of SE value existing disciplines must work collaboratively in multidisciplinary teams (Beasley & O'Neil, 2016; de Graaf, 2014). Lastly, a generic SE Relatics template must be developed within the organization to reduce the dependency of employees on external SE consultants. This stimulates employees to be part in this development, while simultaneously SE experience and knowledge is shared and foundation is created to apply the template.

5.2.3 Client dependency

In every case the SE approach of the corresponding client is different. This is mainly caused by difference in experience with and knowledge of SE. Clients prescribe the SE process of the contractor by establishing project specific SE process requirements in the Specification documentation. In the four cases, importance of certain SE activities is different because clients find specific SE activities more important. The three public clients were Rijkswaterstaat, a Province and a municipality. Rijkswaterstaat uses broadly accepted guidelines and demands for an intensive SE process, whilst the province and the municipality are in general less experienced with SE and therefore rely more on the peoples' specific experience with SE of the involved employees. Some examples of difference in SE approach are:

- In case one, the client specifically stressed on importance of the FA and its output in terms of the FBS and SBS, whilst in the other two cases mainly the SBS was output of the FA and not both the FBS and SBS.
- In case three, the client specifically stressed on the gap between Verification and Validation in the design and realization phase, whilst in other cases this was left to the contractor to decide.

Reef Infra, like many contracting firms, works for many different clients. When the clients' approach to SE and the extent of the prescribed SE process are different for each project, it is challenging for contracting firms to standardize the SE process. Moreover, the contracting firm cannot increase knowledge and experience in applying SE when the application of SE is different in every project.

Important in realizing SE values is to decrease client dependency. To decrease client dependency, contractors must effectively communicate their SE approach with the client (Beasley & O'Neil, 2016). Contractors must discuss their approach to SE with the client to ensure that their SE process is in line with the by the client prescribed SE process (Marchant, 2010). One of the three project success categories of the Iron-triangle is conformance to customers' specifications (Locatelli et al., 2014). To realize SE values and thus increase the chance of delivering the project within budget and schedule, it is crucial that the SE process specifications are clear and understood early in the process. This decreases client dependency further on in the project process and ensures that decisions further on in the execution process are bases on complete information (Marchant, 2010). This strengthens the potion of a contractor in negotiations with the client. The SE approach is clear, the structure of the process is defined and both the contractor and client have a clear understanding of the expected output of SE process.

5.2.4 SE challenges hampering project success

The measurement tool only measures the application of SE activities. It emphasis on the process of SE applied in the projects. Beasley and O'Neil (2016) argue that overemphasis on SE process pushes Systems Thinking, which is one of the core principles of SE, to the background. When SE practitioners become used to the overemphasis on SE process, they often find it challenging to recognize which SE activities to perform and to which level of rigorousness (Beasley & O'Neil, 2016). Therefore, relating SE performance to project success, enables proper recognition of how much SE activity is enough to successfully realize the project. In this paragraph, SE performance is linked to the project success indicators, starting with budget performance.

5.2.4.1 SE performance and project success indicator: Budget

In this paragraph, the budget performance is related to extent of SE application. The graph is presented in the figure below.

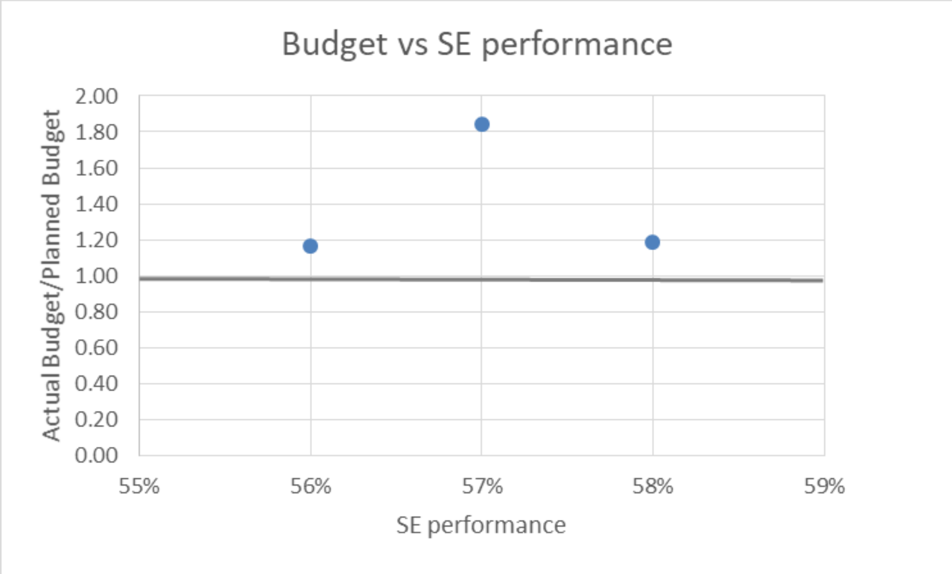

Figure 8: Budget performance set out against SE performance.

The first thing that stands out seems to confirm that when the extent of SE application increases the likelier the project experiences budget overrun. This would be in line with unclear SE procedures, lack of SE skill and knowledge and high degree of client dependency which confirms Reef Infra of not being capable to determine the appropriate extent of SE application necessary for successful budget performance. An SE performance of approximately 56% provides the best budget performance of 1.17.

However, when the project characteristics are considered, the project A348 of case 2 with the highest average extent of SE application of 58% was the most successful for Reef Infra in terms of profitability. This would suggest that a higher extent of SE application results in a better budget performance. Because Reef Infra was selected as contractor after the initial tender, the negotiation position of Reef Infra improved. Reef Infra took more time to analyze project risks and chances. In general, this enabled Reef Infra to improve financial result for Reef Infra.

These results suggest that no clear relation between the extent of SE application and budget performance can be established. There are too many other project specific factors and events during project execution which affect the budget performance of a construction project. For example, in the project of Case 3 Reef Infra did not go to extreme lengths to push the client to pay for additional work to in the end receive a better performance during performance measurements. These performance measurements were part of the BVP methodology applied in the project. In other projects, Reef Infra might not agree to bear some of the costs for additional work, dependent on their bargaining position. Based on the data points, the findings of Honour (2013) and Beasley and O'Neil (2016) cannot be confirmed. The graph does not represent an optimum for SE performance in relation to budget performance.

5.2.4.2 SE performance and project success indicator: Schedule

In this paragraph, the budget performance is related to extent of SE application. The graph is presented in the figure below.

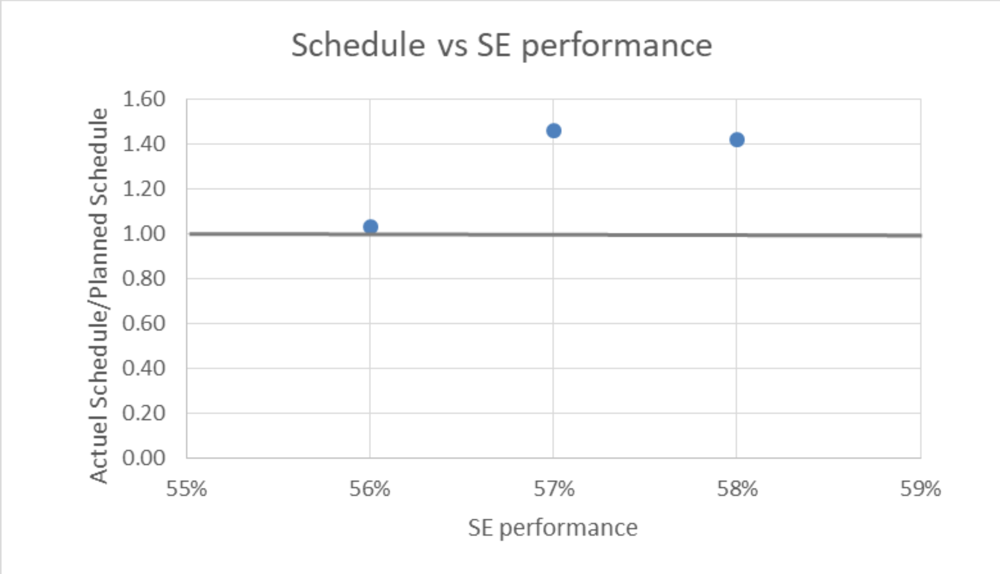

Figure 9: Schedule performance set out against SE performance.

The first thing that stands out seems to confirm that when the extent of SE application increases the likelier the project experiences delays. An SE performance of approximately 56% provides the best schedule performance of 1.03. This would be in line with unclear SE procedures, lack of SE skill and knowledge and high degree of client dependency which confirms Reef Infra of not being capable to determine the appropriate extent of SE application necessary for successful schedule performance.

When the project characteristics are considered, the project Fietsroute Plus Haren of case 3 with the lowest average extent of SE application of 56% was the most successful for Reef Infra in terms of schedule performance. This would suggest that a lower extent of SE application results in a better schedule performance. Although, it is quite clear that no clear relation between the extent of SE application and schedule performance can be established. There are too many other project specific factors and events during project execution which affect the schedule performance of a construction project. For example, in the project of case one an important subcontractor went bankrupt. This resulted in additional time necessary to handover the construction activities to another subcontractor. In another project, bad weather conditions delayed delivery of critical parts of the project. Based on the data points, the findings of Honour (2013) and Beasley and O'Neil (2016) cannot be confirmed. The graph does not represent an optimum for SE performance in relation to budget performance.

5.2.4.3 SE performance and number of RfA's

In this paragraph, the number of RfA's are setup against the extent of SE application. The graph is presented in the figure below.

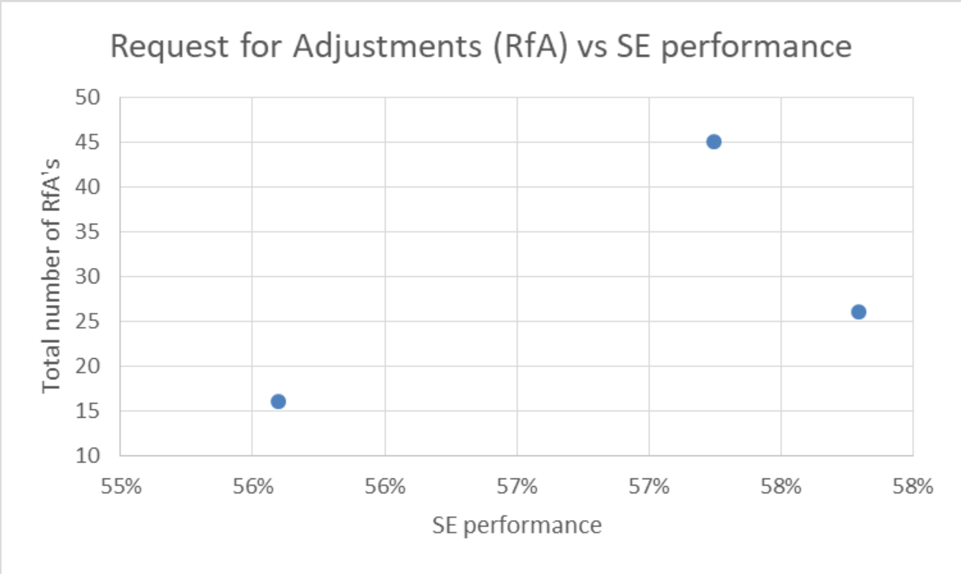

Figure 10: The total number of RfA's set out against SE performance.

The first thing that stands out seems to confirm that when the extent of SE application increases the more RfA's are experienced in the projects. When the Overall SE score increases the number of RfA's increases as well. The project with the highest number of RfA's (45) also scores the highest fulfillment on the base process (66% compared to 54% and 60%). This is in line with the findings of de Graaf (2014). The base process consist of the RA, FA, WBS and Solution Synthesis. This would suggest that improved investment in the RA, FA, WBS and Solution Synthesis provide a more in-depth understanding of the project. Hence, the contracting firm is able to better assess project risks, uncertainties and changes. This provide them with strategy knowledge which enable them to earn more profit on a project by using this knowledge to determine if and how many RfA's will be necessary in the projects. The contractor can then choose to present a specific number less profitable RfA's to the client. The contractor can suggest to bear some of the costs. This would provide them with leverage for bargaining over the more profitable RfA's further on in the realization process.

Moreover, the project with the highest number of RfA's also has the highest budget and schedule overrun. Overall, this project is perceived as unsuccessful. This would suggest that the higher the number of RfA's, the likelier the project is to overrun budget and schedule. This is also confirmed by Honour (2013). When other project characteristics are taken into account, other reasons for a higher number of RfA's can be found. The project with the highest amount of RfA's is also the most complex and largest project of them all. This would confirm the assumption that complexity and scale affect proper in-depth understanding of the project and therefore increase the risk of RfA's. However, this assumption is also a reason why SE must be applied in such projects (Beasley & O'Neil, 2016). Hence, no clear relation between the extent of SE application and number of RfA's can be established based on the data.

6 Conclusions and recommendations

6.1 Conclusions

This research was performed to assess the extent of SE application and project success in civil engineering projects of a medium size contracting firm in the Netherlands. To properly assess the extent of SE application a framework was composed based on existing SE literature regarding the SE application of contractors. This type of assessment was never be done before in the context of a Dutch contracting firm and on such level of detail. Hence, a qualitative research design was composed to provide detailed understanding of the extent of SE application and project success. The case study research method of Yin (2014) was applied and four cases were selected to be appropriate as case study in this research. Within the scope of the research the following research question was answered:

How can a Civil Engineering Contracting Firm measure their Systems Engineering performance and how do these metrics relate to project success indicators budget, schedule and quality?

Based on the results of the research the relation between the extent of SE application and project success cannot be determined. Looking at the graphs, there is no optimum in the extent of SE application in relation to project performance. The findings of Honour (2013) and Beasley and O'Neil (2016) cannot be confirmed, because no clear relation can be established. Moreover, in the cases many other characteristics or events seem to affect the project success. In one case, a subcontractor went bankrupt which caused a lot of delay and cost overrun. In another case, the client and contractor could not reach agreement over the level of detail of the decomposition of requirements. While this is part of the SE process, the reason for disagreement was not caused by the extent of SE application. It was more an organizational issue. The client had not established a project team, while Reef Infra was already handing over official documentation (such as the Verification and Validation plan) for the client to sign off. Case three experienced some delay because of bad weather conditions during the final delivery. To eliminate bias of such characteristics on the relation between the extent of SE application and project success, more assessments of projects using the measurement tool have to be conducted. Overall, project specific events happen to affect project success. Based on the results, it is unclear if a higher or lower extent of SE application could prevent such events from happening. Hence, no clear relation between the extent of SE application and project success in terms of budget, schedule and quality performance can be established.

The results do however confirm that the extent of SE application is different in each project. Although, all projects score an average SE score within a range of approximately 10% because the maximum score was 66% and the lowest score was 56%. The results suggest that SE elements are in some projects not applied while in other projects the same SE elements were applied quite substantially. This means Reef Infra does not apply a comprehensive and standardized SE method in their civil engineering projects. There are multiple reasons for the extent of SE application. First, unclear and out of date SE procedures affect the extent of SE application. Memon et al. (2012, p.50) identified: *"use of up-to-date technology utilization as a mitigation measure to improve budget performance in construction projects"*. In every project the Reef Infra SE handbook was referenced. However, on the project level the handbook was not applied. The procedures within are incomplete, outdated and do not correspond with the SE Relatics templates used in the projects. This made employees to base the extent of SE application solely on their own experience with and knowledge of SE. Update work procedures enable proper coordination of the SE process. Coordination is a key factor for the success of construction projects, according to Jha and Iyer (2007). Second, the level of SE skill and knowledge affected the extent of SE application. In all four cases, external Systems Engineers are taken on to supply the SE Relatics template and guide the SE process in the project. This made the SE handbook even more redundant and resulted in employees becoming dependent on the external consultants. Moreover, little knowledge was shared within the organization. In some projects there were project specific solutions to SE challenges. These were not actively shared within the organization. Trained, committed and competent project participants positively influence the successful completion of the project (Tabish Syed Zafar & Jha Kumar, 2012, p.1137). Proper competences enable the project team to make timely decisions ensuring that the project remains on schedule and within budget. Third, Reef Infra is highly dependent on the client for the extent of SE application. The clients competence is one of the major success factors affecting budget, schedule and quality performance (Jha & Iyer, 2007). Higher level public clients (Rijkswaterstaat) apply clear and well established SE standards because the client had much experience with and knowledge of SE. Lower level public clients (Province and Municipality) had not much experience with SE which caused overinvestment and underinvestment in the SE process.

Establishing clear SE procedures, enhancing SE skill and knowledge and reducing client dependency enable the contractor to properly assess the extent of SE necessary to realize project success. Not one rigid SE management approach is appropriate for all different types of projects (Beasley, 2017b; Beasley & O'Neil, 2016; Sauser, 2006). A contingency approach to SE in construction projects can prevent over- and underinvestment. *"Such an approach iterates between project characteristics and project type to define the appropriate managerial approach to SE"* (Sauser, 2006, p.214). Beasley and O'Neil (2016) argue that overemphasis on SE process pushes Systems Thinking, which is one of the core principles of SE, to the background. When SE practitioners become used to the overemphasis on SE process, they often find it challenging to recognize which SE activities to perform and to which level of rigorousness (Beasley & O'Neil, 2016). Therefore, relating SE performance to project success, enables proper recognition of how much SE activity is enough. The approach to SE must be corresponding with the characteristics of the project, otherwise SE does not provide value delivering in the project. Different projects require different variations on the SE process within the broader SE strategy of the organization (Beasley & O'Neil, 2016). Although, the measurement tool developed in the research emphasizes on the extent of SE process applied in the project, it does provide the contracting firm with the necessary information to target underperforming SE tasks. Overall, to ensure that the contractor is capable of approach SE as a flexible process and not to overemphasize on SE tools it is important the contractor must establish clear SE procedures, enhance SE skill and knowledge and reduce client dependency.

To conclude, based on the qualitative case study research findings the SE process framework is applicable to assess the extent of SE application. The output of the measurement tool provide contractors with vital information to improve their SE process. Moreover, three specific factors affecting the extent of SE application are derived from the results. Based on the results no clear relation could be established between the extent of SE application and project success in terms of budget, schedule and quality. However, the findings do suggest when more projects are assessed using the measurement tool a relation can be established and the bias effect of other characteristics and events that also affect project success can be eliminated.

6.2 Recommendations Reef Infra

The results of this research suggest multiple recommendations for Reef Infra to improve their SE performance. First, Reef Infra must update work procedures. Secondly, Reef Infra must improve SE skill and knowledge. Third and final, Reef Infra must decrease client dependency.

6.2.1 Update work procedures

To improve the SE performance, Reef Infra must update work procedures to reflect the current SE strategy in their projects. The work procedures are subdivided into the SE handbook and the UAV-ic Realization management process. Both procedures are incomplete regarding the application of the SE process in practices. Validation is mentioned, however there is no clear validation process specified in both procedures. The procedures described in the SE handbook and UAV-ic Realization management process are rigid. This means that a "one solution fits all" approach is applied in structuring both procedures. The results suggest a more flexible approach to SE is necessary to prevent over- and/or underinvestment. The approach to SE must be corresponding with the characteristics of the project, otherwise SE does not provide value delivering in the project. Different projects require different variations on the SE process within the broader SE strategy of the organization (Beasley & O'Neil, 2016). SE is often applied within an existing organization, successful adoption of SE require significant consideration for SE implementation and commitment of leadership (Beasley & O'Neil, 2016). The following questions must be asked in determining the appropriate extent of SE application:

- What project characteristics can affect the project success?
- Is there enough SE skill and knowledge within the project team?
- What specific SE tasks does the client demands?
- What specific SE tasks are performed in Relatics and why?

A specific validation process must be added to SE handbook. The suggested validation process is presented in figure 11.

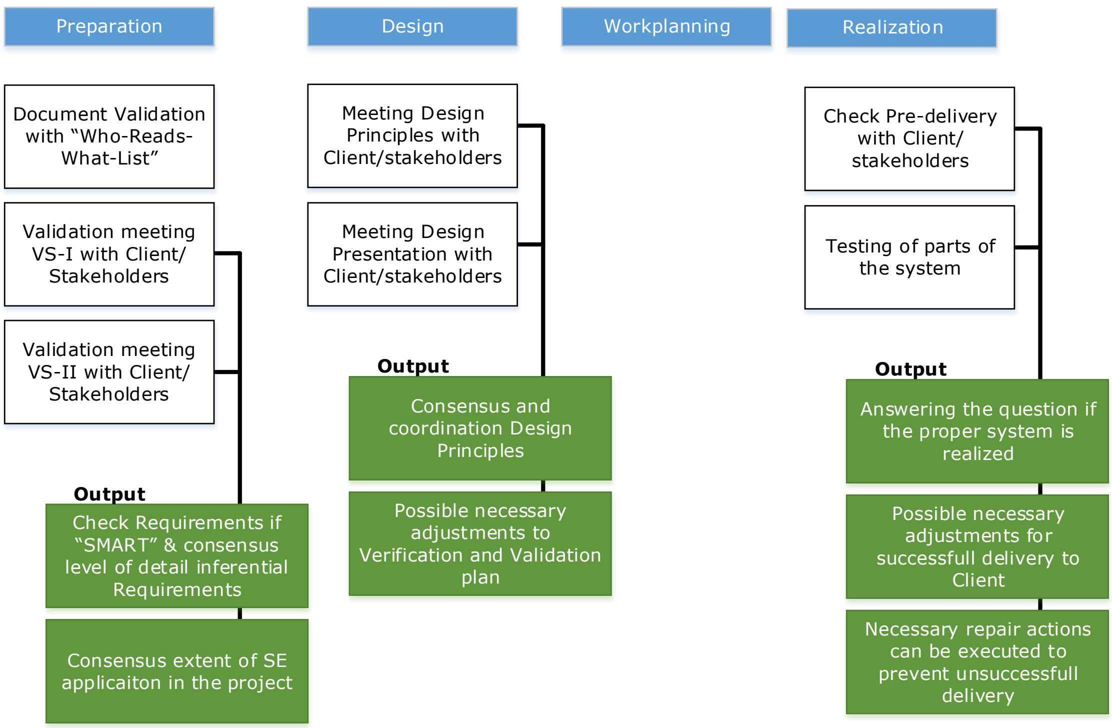

Figure 11: Suggested Validation process.

6.2.2 Improve SE skill and knowledge

Reef Infra must improve SE skill and knowledge to enable their employees to successfully determine the appropriate extent of SE application in the projects. The balance between being systematic and being systemic, is important. Being systematic means that proper work procedures are applied. Being systemic means that proper skills are applied. "*When there is strong focus on the SE process and less on SE skills the process can appear overly bureaucratic and onerous. When there is strong focus on SE skills and less on the SE process there is no control. This means that skilled individuals are "uninterested" in the process, critical tasks are often incomplete and there is much reinvention of best practices."* (Beasley, 2017a, p.8). The right balance between skills and process is important to realize the values of SE (Beasley, 2017a).

To achieve the proper balance, the whole organization must be "Systems Engineered", according to Beasley (2017a). The main purpose of applying SE is to fully understand the extensiveness of the problems which the system to be realized has to solve. Therefore SE must not be a separate department within an organization, but it must be integrated in every layer of an organization. This means that the following items must be defined in the SE strategy of an organization:

- The SE process;
- The competencies necessary for practitioners to perform the process;
- The tools and techniques used in performing the process.

The competencies of practitioners are controlled by the SE process and enabled by the tools and techniques which are part of the process. Although, SE must be gradually integrated into an organization. Part of this gradual process must be to share overall SE best practices and project specific SE solutions within the organization. Furthermore, Reef Infra must approach SE as a team effort. Establishing multidisciplinary teams enable sharing of knowledge and experience across the borders of one's own discipline. All parts of an organization must be involved in defining and implementing the SE strategy to as low as the project level itself (Elliott et al., 2012).

6.2.3 Decrease client dependency

The competence of the client regarding SE affects the extent of SE application of Reef Infra. Different clients approach SE differently, whereas higher level public clients demand a more thorough SE process compared to lower level public clients. Instead of rigid application of SE processes, quality of systems practice can be improved by appropriate flexibility in the SE approach (Beasley & O'Neil, 2016, p.5). Reef Infra can achieve this flexibility by performing a validation activity of the by the clients' prescribed SE process. In creating foundation for decisions regarding the SE process communication is important (Bonnema, Veenvliet, & Broenink, 2016). The client's approach to SE is aligned with the UAV-ic realization management process of Reef Infra. In this validation activity, the specification documentation (Vraagspecificatie I en II) is discussed with the client to reach consensus. This prevents under- and/or overinvestment in the SE process. Moreover, foundation for the chosen SE process is simultaneously generated. Further on in the realization process, Reef Infra can only benefit from the foundation by the client.

6.2.4 Commitment to SE process

After Reef Infra established clear and up-to-date SE procedures, improved SE skill and knowledge and decreased client dependency, Reef Infra must commit to the SE strategy applied in their projects. Commitment influences project success. Commitment keeps the project team motivated to execute the project according to the proper work procedures, which ensure the realization of a successful project. Management support is necessary to maintain control that the project team is committed to the established SE process (Beasley & O'Neil, 2016; de Graaf, Vormer, et al., 2017). Within the organization of Reef Infra, internal SE Champions and Advocate are necessary. The A SE champion is defined as: *"Champions understands the value of SE, accepts it and pulls for the application of SE within the organization"* (Beasley & O'Neil, 2016, p.13) and the SE advocate is defined as: "*The Advocate has a deeper understanding of SE and how to adjust the SE process on the organizational needs. The Advocate provide the structure of the process to in the end ensure that the SE implementation consistently delivers value*." (Beasley & O'Neil, 2016, p.14). Both roles must be assigned in both the broader context of the organization and the context of a project. This ensures continuous improvement of SE on the organizational level and proper adjustment of the SE process on the project level.

6.3 Limitations and recommendations for future research

This research has three main limitations. First and foremost, the conclusions drawn in this research are based on limited data points. Four case studies were applied to develop the measurement tool and to gather SE performance metrics. For three out of the four cases also Project success metrics were gathered. A qualitative research design was chosen to develop the measurement tool, which was the main objective in this research. However, to be able to draw more solid conclusions regarding how the extent of SE applied affects project success, more data points must be gathered. A more extensive quantitative study should be performed with the measurement tool. In addition, such a study also further strengthens the measurement tool.

The second limitation of this research is the limited amount of project success indicators incorporated in the research. Only the indicators budget and schedule are within the scope of the research. Recent literature criticizes the constrained nature of the "Iron-triangle" of project success. Also more subjective success characteristics, such as Stakeholder Satisfaction, must be considered in analyzing how the extent of SE application affects project success. Furthermore, SE is perceived to also deliver value for such subjective success characteristics. Future research can expand project success dimension to product success and organizational success, as described by McLeod et al. (2012).

Third and final, contractors seem highly dependent on clients and subcontractors for their SE process performance. More studies regarding how SE performance of subcontractors and clients affect the SE process of a contractor must be conducted. This was intentionally left out of the scope of this research.

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Appendices

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1 Appendix – Quick Scan projects

1.1 Procedure

The procedure for selecting cases is according to the Quick Scan method of Yin (2014). More specific, the one-phase screening approach is applied to provide a selection of projects. Then the appropriateness of the projects is determined based on multiple selection criteria. The appropriateness of the cases is discussed with involved employees of Reef Infra and research experts.

Selection criteria candidate cases		Reason
7.	In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.	Scope
8.	A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.	Comprehensive overview of SE application
9.	The used contract in the project is based upon UAC-ic.	Scope
10.	The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.	Recent SE paradigms applied
11.	The main contractor applied Systems Engineering.	Scope
12.	There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.	Comprehensive overview of SE application

1.2 Projects

Project	Contact person
Meppelerdieplsuis	Niek van Bentheim
A348	Koen Naafs
Fietsroute Plus Haren	Martin Meijer
N34	Peter Blom
De Groene Loper A2	Gerben Vossebelt
Noorderbrug Tracé	Mark Vlaanderen-Oldenzeel
Fietstunnel Doetichem	Jan Hendrik Fischer

1.2.1 Project 1: Meppelerdiepsluis [MDS-WA]

Goal: Benchmark SE application according to SE-methodology of Reef Infra/Strukton Civiel Projecten.

Project characteristics
Discipline: Hydraulic engineering
Client: Rijkswaterstaat
Tender procedure: Economical Most Advantageous Tender (EMAT)
Contract: UAV-ic

Short project description
"De ombouw van de Meppelerdiepsluis is gestart in het eerste kwartaal van 2013 en is naar verwachting in 2017 afgerond. De Combinatie Strukton Civiel Projecten - Reef Infra is hoofdaannemer van dit Rijkswaterstaatproject. Het ontwerp is uitgevoerd door Antea Group. De staalconstructie (roldeuren en nieuwe brug) wordt geleverd door Iemants. De waterbouwkundige constructies worden uitgevoerd door Heuvelman Ibis en de sloopwerkzaamheden rondom het huidige sluishoofd worden door de firma Vlasman uitgevoerd."

Review

- In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.
    - Reef Infra executes the project in combination with Strukton Civiel.

- A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.
    - This project is one of the few hydraulic engineering projects which Reef Infra performed in the last 5 years. Moreover, this project is one of the few larger and more complex projects Reef Infra has performed.

- The used contract in the project is based upon UAC-ic.
    - The project has a contract based upon UAC-ic.

- The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
    - The project is delivered in December 2017. The delivery dossiers are final.

- The main contractor applied Systems Engineering.
    - Yes, Reef Infra invested highly in the SE process of the project. The project was the first test case for implementation of SE in large and complex projects. Strukton Civiel was invited to assist in implementing SE.

- There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.
    - The amount of available documentation is extensive. Moreover, the SE process was centralized because it was completely performed in Relatics.

Conclusions
This project is appropriate to be analyzed in the case study because of it characteristics. Moreover, Reef Infra invested highly in the SE process, because the client demanded so. There is enough documents available to provide a comprehensive picture of the SE process.

1.2.2 Project 2: Vervangen bruggen perceel A348 [A348-BB]

Goal: Benchmark SE application according to SE-methodology of Reef Infra.

Project characteristics
Discipline: Concrete Engineering
Client: Provincie Gelderland
Tender procedure: Economical Most Advantageous Tender (EMAT)
Contract: UAV-ic

Short project description
"De bestaande viaducten zijn aan het einde van hun 100 jaar technische levensduur. De nieuwe viaducten zijn ontworpen en worden gebouwd voor een levensduur van 100 jaar. Om de werkzaamheden te realiseren zijn er een aantal maatregelen getroffen. Zo is een rijstrook van de viaducten tijdens de werkzaamheden open voor verkeer. Daarnaast zijn de wegen onder de viaducten slechts drie weekenden per viaduct afgesloten voor doorgaand verkeer om het sloopwerk uit te kunnen voeren."

Review

- In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.
  - Reef Infra executes the project.

- A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.
  - This project is of mediocre complexity and size. The main discipline involved in the project is concrete engineering. This is a project which represents the common project portfolio of Reef Infra. Moreover, the client is experienced with SE but not as much as the client in project 1. This combination of characteristics makes this project a proper representation of the majority of construction projects and the SE application within.

- The used contract in the project is based upon UAC-ic.
  - The project has a contract based upon UAC-ic.

- The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
  - The project is delivered in February 2017. The delivery dossiers are final.

- The main contractor applied Systems Engineering.
  - Yes, Reef Infra applied some SE best practices in the SE process of the project. Reef Infra had some experience in applying SE in their construction projects.

- There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.
  - The amount of available documentation is extensive. Moreover, the SE process was centralized because it was completely performed in Relatics.

Conclusion
This project is appropriate to be analyzed in the case study because of it characteristics. Reef Infra was more experienced with SE and some SE best practices are applied in the project. Moreover, the client was less demanding and relied more on the expertise of Reef Infra. There is enough documents available to provide a comprehensive picture of the SE process.

1.2.3 Project 3: Fietsroute Plus Haren [FPH-WE]

Goal: Relate SE application to benchmark projects.

Project characteristics
Discipline: Infrastructure
Client: Gemeente Haren
Tender procedure: Best Value Procurement (BVP)
Contract: UAV-ic

Short Project description
"De gemeente Haren werkt samen met de gemeente Groningen, provincie Groningen en de Regio Groningen-Assen aan het verbeteren van de fietsverbinding tussen Haren en Groningen. De route Jachtlaan – Kromme Elleboog - Kerklaan met aansluiting op de Helperzoom wordt opgewaardeerd tot een Fietsroute Plus. Dit is een hoogwaardige fietsverbinding waarbij extra kwaliteit wordt geboden. Deze route is uitgewerkt tot een schetsontwerp waarbij nog een aantal keuzes gemaakt moeten worden."

Review

- In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.
    - Reef Infra executes the project.

- A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.
    - This project is of small complexity and size. The main discipline involved in the project is infrastructure. This was one of the first BVP project which Reef Infra had in their portfolio. This made Reef Infra eager to perform well. Moreover, the client was inexperienced with SE. Nonetheless, the client tried hard to prescribe a solid and intensive SE process. This made Reef Infra to overinvest in their SE process, if the complexity of the project is taken into account.

- The used contract in the project is based upon UAC-ic.
    - The project has a contract based upon UAC-ic.

- The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
    - The project is delivered in December 2017. The delivery dossiers are final.

- The main contractor applied Systems Engineering.
    - Yes, Reef Infra followed the SE process prescribed by the client. Reef Infra had some experience in applying SE in their construction projects.

- There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.
    - The amount of available documentation is extensive. Moreover, the SE process was centralized because it was completely performed in Relatics.

Conclusion
This project is appropriate to be analyzed in the case study because of it characteristics. Reef Infra was to some extent inexperienced in applying SE and the client was inexperienced with applying SE. However, this made Reef Infra eager to perform well. Reef Infra followed the by the client prescribe intensive SE process. There is enough documents available to provide a comprehensive picture of the SE process.

1.2.4 Project 4: N34 Witte Paal – Drentse Grens [N34 – WE]

Goal: Relate SE application to benchmark projects.

Project characteristics
Discipline: Infrastructure
Client: Provincie Overijssel
Tender procedure: EMAT
Contract: UAV-ic

Short project description
"De combinatie FLOOW realiseert voor de provincie Overijssel op de provinciale weg N34 nieuw asfalt en ongelijkvloerse kruisingen. De weg wordt verbeterd en veiliger gemaakt. Op dit moment is de N34 nog niet ingericht als regionale stroomweg. Er zijn nog veel gelijkvloerse kruisingen met verkeerslichten en uitritten van woningen aanwezig. Combinatie FLOOW gaat de weg inrichten als een stroomweg. Dat betekent dat de gelijkvloerse overgangen verdwijnen en het verkeer zo veilig met 100 km per uur over de weg kan rijden."

Review

- In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.
  - Reef Infra executes the project.
- A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.
  - This project is of high complexity and large scale. Multiple disciplines are involved in the project. This project is of great importance for Reef Infra because of its impact in the surroundings. The client is to some extent experienced with SE and Reef Infra applied some best practices in the project.
- The used contract in the project is based upon UAC-ic.
  - The project has a contract based upon UAC-ic.
- The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
  - The project is yet to be delivered. One third of the project is delivered early 2018.
- The main contractor applied Systems Engineering.
  - Yes, Reef Infra applied some SE best practices in the project. Reef Infra had some experience in applying SE in their construction projects.
- There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.
  - The amount of available documentation is extensive. Moreover, the SE process was centralized because it was completely performed in Relatics.

Conclusion
This project is appropriate to be analyzed in the case study because of it characteristics. There is enough documents available to provide a comprehensive picture of the SE process. However, the project is yet to be delivered. One third of the project is pre-delivered early 2018. The SE process for these parts are finalized, enabling proper assessment of SE performance in the project. However, it is impossible to measure project success in terms of budget, schedule and quality performance because the project is not completely delivered.

1.2.5 Project 5: De Groene Loper A2

Goal: none.

Project characteristics
Discipline: Area development
Client: Rijkswaterstaat and Municipality Maastricht
Tender procedure: Competitive dialogue
Contract: UAV-ic

Short project description
"In 2011 startte Avenue2 met voorbereidende werkzaamheden zoals het verleggen van kabels, leidingen en riolering, bodem- en archeologieonderzoek, kappen van bomen en sloop van de eerste flats voor A2 Maastricht. In 2012 ging de bouw van de tunnel, na het verlenen van de omgevingsvergunning, definitief van start. Ook vonden vanaf toen steeds meer activiteiten plaats voor de ombouw van knooppunt Kruisdonk."

Review

- In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.
  - Strukton Civiel Projecten performs the project.

- A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.
  - This project is of high complexity and large scale. Multiple disciplines are involved in the project. The project is unique in its tender procedure. With the use of the competitive dialogue possible contractors were involved early in the project development process which is normally performed by the client. The client is to some highly experienced with SE.

- The used contract in the project is based upon UAC-ic.
  - The project has a contract based upon UAC-ic.

- The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
  - The project is yet to be delivered.

- The main contractor applied Systems Engineering.
  - Yes, Strukton Civiel Projecten applied SE.

- There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.
  - The amount of available documentation is extensive. Moreover, the SE process was centralized because it was completely performed in Relatics.

Conclusion
This project is not appropriate to analyze in the case study. The SE process applied is not performed by employees of Reef Infra. Overall, few employees of Reef Infra are involved in the project. Also, the complexity and scale and the uniqueness of the tender procedure, make the project incomparable to the other cases.

1.2.6 Project 6: Noorderbrug Tracé

Objective: None.

Project characteristics
Discipline: Infrastructure
Client: Belvédère Wijkontwikkelingsmaatschappij B.V.
Tender procedure: Competitive dialogue
Contract: UAV-ic

Short project description
"De nieuwe A2-tunnel in Maastricht-Oost verbetert de verkeersdoorstroming in noord-zuid richting in onze stad. Het project Noorderbrugtracé sluit hier op aan en zorgt voor een betere doorstroming van het Maaskruisende verkeer aan de noordkant van de stad. Inclusief een snellere verbinding met België (Lanaken/Smeermaas) en een goede aansluiting op het wegennet in Maastricht-West. Hiervoor wordt aan de noordzijde van de (binnen)stad tussen 2015 en 2018 een geheel nieuwe verkeersstructuur gerealiseerd."

Review

- In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.
  - Strukton Civiel Projecten performs the project, Reef Infra is almost not involved.
- A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.
  - This project is of high complexity and large scale. Multiple disciplines are involved in the project. The project is unique due to its complexity and scale.
- The used contract in the project is based upon UAC-ic.
  - The project has a contract based upon UAC-ic.
- The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
  - The project is delivered.
- The main contractor applied Systems Engineering.
  - Yes, Strukton Civiel Projecten applied SE.
- There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.
  - The amount of available documentation is extensive. However, accessibility to documentation proses to be more challenging.

Conclusion
This project is not appropriate to analyze in the case study. The SE process applied is not performed by employees of Reef Infra. Overall, few employees of Reef Infra are involved in the project. Also, the complexity and scale, make the project incomparable to the other cases.

1.2.7 Project 7: Fietstunnel Doetichem

Objective: None.

Project characteristics
Discipline: Infrastructure
Client: Belvédère Wijkontwikkelingsmaatschappij B.V.
Tender procedure: Competitive dialogue
Contract: UAV-ic

Short project description
"De nieuwe A2-tunnel in Maastricht-Oost verbetert de verkeersdoorstroming in noord-zuid richting in onze stad. Het project Noorderbrugtracé sluit hier op aan en zorgt voor een betere doorstroming van het Maaskruisende verkeer aan de noordkant van de stad. Inclusief een snellere verbinding met België (Lanaken/Smeermaas) en een goede aansluiting op het wegennet in Maastricht-West. Hiervoor wordt aan de noordzijde van de (binnen)stad tussen 2015 en 2018 een geheel nieuwe verkeersstructuur gerealiseerd."

Review

- In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.
    - Reef Infra performs the project.

- A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.
    - This project is of average scale and complexity. The project would properly reflect the project portfolio of Reef Infra.

- The used contract in the project is based upon UAC-ic.
    - The project has a contract based upon UAC-ic.

- The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.
    - The project is delivered.

- The main contractor applied Systems Engineering.
    - Yes, Reef Infra applied SE. However, due to the client not being experience with SE, the extent of the application of SE is very limited. This would not reflect the SE application of Reef Infra.

- There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.
    - The amount of available documentation is not as extensive as necessary.

Conclusion
This project is not appropriate to analyze in the case study. The extent of the SE process is limited and not reflecting the average SE application of Reef Infa.

1.2.8 Overview

Project name	Appropriate [Yes/No]
Meppelerdiepsluis [MDS-WA]	Yes
Vervangen bruggen perceel A348 [A348-BB]	Yes
Fietsroute Plus Haren [FPH-WE]	Yes
N34 Witte Paal – Drentse Grens [N34 – WE]	Yes, but only as test case for the application of SE
De Groene Loper A2	No
Noorderbrug Tracé	No
Fietstunnel Doetichem	No

2 Appendix - Case study protocol

1 Introduction

The case study protocol is based upon the method of (Yin, 2014) and it describes the procedure for data collection and analysis. The protocol is setup to increase reliability of the findings. The case study protocol consists of the following items:

a. Overview of the case study
b. Data collection procedures
c. Data collection questions
d. Guide for the Case study report

2 Overview of the case study

2.1 Research design

The research design provides structure and is based on the research background and goals. The analytical framework presents how the research project is supposed to achieve the research goals.

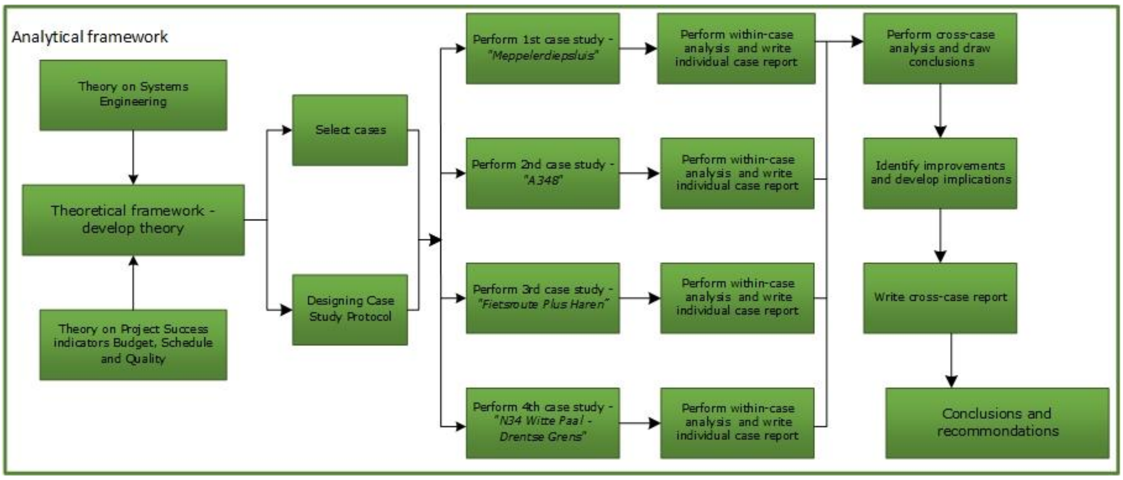

Figure 12: Analytical framework based on multi-case study design by Yin (2014).

2.2 Case study research

The research design is based on the method of Yin (2014). The method of Yin (2014) and why this method is appropriate for this research project is explained in the following paragraphs.

2.2.1 Multi-Case Design

In this research we investigate and try to establish the relation between SE performance and achievement of common BVP objectives. The relation between SE and BVP in the Dutch construction industry is until now not investigated. Honour (2013) initiated an investigation, but his research was limited to Military programs in English-speaking countries. Therefore, the multi-case design is of explorative nature investigating the relation between SE and BVP. This means that there are no propositions structuring the research project, making the rationale in the research design the only way to state purpose (Yin, 2014). The rationale is explained in Chapter 2. When evidence is gather in multiple projects over a full variety of disciplines (Infrastructure and Hydraulic and Concrete Engineering) the evidence is considered to be more compelling (Yin, 2014). The multi-case design enables the researcher to apply literal replication establishing a comprehensive understanding of SE performance and how this performance realizes common BVP objectives.

Literal replication is applied because the amount of appropriate cases is limited, maximum of four projects. The problem owner does not have many recent projects under UAC-ic in their portfolio.

2.2.2 Unit of analysis

Looking back at the research questions, it is important that the unit of analysis represents the full spectrum of projects realized by the problem owner. Only then a comprehensive overview of SE performance and how this performance ensures realization of common BVP objectives is established. The selection of case studies is done based upon the one-phase approach by Yin (2014). After an initial search on the website of Reef Infra and "mini-interviews" with employees of Reef Infra connected with the projects, there were only 6 cases appropriate for this research. This selection is done based upon several selection criteria. These selection criteria are based upon the literature study and previous research.

The selected cases
The output of the case study selection and therefore the selected cases are as follows:

5. Meppelerdiepsluis, involved discipline(s): hydraulic and concrete engineering;
6. A348, involved discipline(s): concrete engineering;
7. Fietsroute Plus Haren, involved discipline(s): infrastructure;
8. N34 Witte Paal- Duitse Grens, involved discipline(s): infrastructure;
9. ~~A2 Groene Loper;~~
10. ~~Noorderbrugtracé.~~
11. ~~Fietstunnel Doetichem~~

An extensive description of the selected cases is in appendix I.

2.2.3 Data collection strategy

Important is that all the case studies are mutual comparable to be able to combine findings of the within-case and cross-case analyses. This is ensured by applying the same case study protocol in each of the cases. The case study protocol is in appendix I. Yin (2014) defined four principles of data collection.

Use multiple sources of evidence
Many sources of evidence making case study findings or conclusions likely to be more convincing and accurate. Using multiple sources of evidence enables triangulation. Yin (2014) describes four types of triangulation: data triangulation, investigator triangulation, theory triangulation and methodological triangulation. Data and methodological triangulation is achieved by using document analysis and conducting unstructured interviews as two main sources of evidence. Investigator triangulation is achieved by discussing the case study protocol, data and results with senior researchers. Theory triangulation is achieved by applying pattern-matching which compares theoretical patterns with empirical patterns.

Create a case study database
The data is put in a large Excel file. This Excel file is developed as a measurement tool, but it also functions as a database of all the collected data in this research. For each case study the collected documentation is put in the same folder as the case study report.

Maintain chain of evidence
By defining a case study protocol, we maintain the chain of evidence. The case study protocol ensures that in every case study data is collected and analyzed in the same way and in such a way that an external observer is able to follow derivation of any evidence. This also enables the researcher to perform cross-case analysis.

Exercise care when using data from electronic sources

The case study protocol also ensures care when using data from electronic sources. The protocol describes the scope and boundaries of the case studies. The scope and boundaries limit the researcher to a demarcated area of theories.

2.2.4 Data analysis strategy

Within-case analysis

After collecting the SE metrics and BVP objective metrics, the within case analysis is performed. In this analysis the performance for every SE task are compared to see if there are differences or similarities. The objective of this analysis is to determine if the contracting firm is able to better implement specific SE tasks and if the contracting firm is able to better achieve certain BVP objectives. Some SE tasks are more related to certain BVP objectives than other tasks. For example, when the validation and verification is performed in a well-structured and intensively documented manner one can presume that there are less remnant points in the delivery. Following this logic, there are more SE tasks which relate more specifically to certain BVP objectives. The within-case analysis enables the opportunity to fulfill the goal within the research.

Cross-case analysis

After the extent of the SE application and achievement of BVP objectives in every case is clear these metrics can be mutually compared. This is done in a cross case analysis. The cross-case analysis is done to understand the possible relations between the SE metrics and BVP objectives metrics and to clarify and utilize the link between SE metrics and BVP metrics. The fulfillment for each SE task and BVP objective in every project is compared and possible patterns are appointed. In the cross-case analysis certain links in specific cases are analysis by verification in other case studies. Lastly, by clarifying the links between SE metrics and BVP metrics and measuring the fulfillment of both, it might become possible to be able to suggest improvements in the SE application and the achievement of BVP objectives. The cross-case analysis enables the opportunity to fulfill the goal of the research.

2.3 Problem statement

The problem statement set the boundaries for the case studies. We observe the problems mentioned in the problem statement in the case studies. The objective is to understand and be able to suggest improvements to overcome these problems. This answers the research questions.

Reef Infra finds it challenging to increase standardization, independency, and overall performance regarding their SE process and finds it also challenging to collect performance information to SE related tasks. Reef Infra is highly dependent on clients for the extent of SE application as clients determine for large parts how Reef Infra must apply SE in their projects. Reef Infra is also highly dependent on subcontractors because large parts of the work is subcontracted making subcontractors responsible for great deal of the input in Reef Infra's SE process. SE is a relative new way of working for clients and subcontractors. This leads to a lot of insecurity (within the organization of clients and subcontractors), struggle and discussion between Reef Infra and their clients and between Reef Infra and their subcontractors. Reef Infra is looking for opportunities to measure their SE performance to find or identify opportunities for improvement. Measuring their SE performance enables them to target underperforming SE tasks. Alongside their wish to improve their SE application, Reef Infra also wants to become more successful in BVP. To become more successful Reef Infra has to collect performance information. Reef Infra finds it challenging to collect SE performance information and how to relate these measurements to common project success indicators budget, schedule and quality which are commonly used in BVP tenders. When they are able to quantify this relation, Reef Infra can prove that their control over the SE process contributes to common project success indicators. This could provide interesting performance information which Reef Infra can use in BVP.

A comprehensive observation of Reef Infra's SE application is necessary to assist Reef Infra in improving their SE application and to develop simultaneously a measurement tool to collect performance information. For this reason, in this case study some projects were selected and analyzed to observe Reef Infra's SE application. Observations combined with the literature study form the input necessary to develop a measurement tool and to suggest improvements in Reef Infra's SE application.

In the case study, we try to find the answers to the following research questions:

1. How can the performance of Systems Engineering be measured?
2. How can project success indicators budget, schedule and conformance to clients' specification be measured?
3. Which link is there between Systems Engineering metrics and project success indicators budget, schedule and conformance to clients' specifications?
4. To what extent can this link be clarified and understood?

2.4 Audience

There is an audience involved in the case study. The audience is directly involved with the selected projects and are most likely the process manager or technical manager. The process manager oversees the SE process in the design phase, while the technical manager oversees the SE process during the execution phase.

3 Data collection procedures

3.1 Selecting data sources

The following selection criteria are applied to select the projects which are appropriate for the research according to the research design. The One Phase Screening Approach (Yin, 2014) was used to select the projects in a structured manner.

Table 14: Seven selection criteria to determine if projects are appropriate as case study.

Selection criteria candidate cases		Reason
1.	In the project Strukton Civiel, Reef Infra or a combination of both is the main contractor.	Scope
2.	A variety of types of projects are chosen to provide a comprehensive overview of the application of Systems Engineering.	Comprehensive overview of SE application
3.	The used contract in the project is based upon UAC-ic.	Scope
4.	The project is recently delivered or almost delivered, whereas at least the delivery dossier is present.	Recent SE paradigms applied
5.	The main contractor applied Systems Engineering.	Scope
6.	There is enough documentation available to analyze the application of Systems Engineering. At least a Verification and Validation plan and a Verification and Validation report is available.	Comprehensive overview of SE application

The selection criteria resulted in the following selected projects. For each of the projects the following aspects are briefly described:

- Purpose of the project in the multi-case study research model;
- Relevant project data, such as:
  - Discipline (infrastructural, hydraulic or areal development);
  - The client;
  - The applied tender procedure;
  - The contract of the project;
  - The project size displayed as budget of the project;
- A brief description of the project.

3.2 Unit of analysis

3.2.1 Project 1: Meppelerdiepsluis [MDS-WA]

Goal: Benchmark SE application according to SE-methodology of Reef Infra/Strukton Civiel Projecten.

Project characteristics
Discipline: Hydraulic engineering
Client: Rijkswaterstaat
Tender procedure: Economical Most Advantageous Tender (EMAT)
Contract: UAV-ic

Short project description
"De ombouw van de Meppelerdiepsluis is gestart in het eerste kwartaal van 2013 en is naar verwachting in 2017 afgerond. De Combinatie Strukton Civiel Projecten - Reef Infra is hoofdaannemer van dit Rijkswaterstaatproject. Het ontwerp is uitgevoerd door Antea Group. De staalconstructie (roldeuren en nieuwe brug) wordt geleverd door Iemants. De waterbouwkundige constructies worden uitgevoerd door Heuvelman Ibis en de sloopwerkzaamheden rondom het huidige sluishoofd worden door de firma Vlasman uitgevoerd."

3.2.2 Project 2: Vervangen bruggen perceel A348 [A348-BB]

Goal: Benchmark SE application according to SE-methodology of Reef Infra.

Project characteristics
Discipline: Concrete Engineering
Client: Provincie Gelderland
Tender procedure: Economical Most Advantageous Tender (EMAT)
Contract: UAV-ic

Short project description
"De bestaande viaducten zijn aan het einde van hun 100 jaar technische levensduur. De nieuwe viaducten zijn ontworpen en worden gebouwd voor een levensduur van 100 jaar. Om de werkzaamheden te realiseren zijn er een aantal maatregelen getroffen. Zo is een rijstrook van de viaducten tijdens de werkzaamheden open voor verkeer. Daarnaast zijn de wegen onder de viaducten slechts drie weekenden per viaduct afgesloten voor doorgaand verkeer om het sloopwerk uit te kunnen voeren."

3.2.3 Project 3: Fietsroute Plus Haren [FPH-WE]

Goal: Relate SE application to benchmark projects.

Project characteristics
Discipline: Infrastructure
Client: Gemeente Haren
Tender procedure: Best Value Procurement (BVP)
Contract: UAV-ic

Short Project description
"De gemeente Haren werkt samen met de gemeente Groningen, provincie Groningen en de Regio Groningen-Assen aan het verbeteren van de fietsverbinding tussen Haren en Groningen. De route Jachtlaan – Kromme Elleboog - Kerklaan met aansluiting op de Helperzoom wordt opgewaardeerd tot een Fietsroute Plus. Dit is een hoogwaardige fietsverbinding waarbij extra kwaliteit wordt geboden. Deze route is uitgewerkt tot een schetsontwerp waarbij nog een aantal keuzes gemaakt moeten worden."

3.2.4 Project 4: N34 Witte Paal – Drentse Grens [N34 – WE]

Goal: Relate SE application to benchmark projects.

Project characteristics
Discipline: Infrastructure
Client: Provincie Overijssel
Tender procedure: EMAT
Contract: UAV-ic

Short project description
"De combinatie FLOOW realiseert voor de provincie Overijssel op de provinciale weg N34 nieuw asfalt en ongelijkvloerse kruisingen. De weg wordt verbeterd en veiliger gemaakt. Op dit moment is de N34 nog niet ingericht als regionale stroomweg. Er zijn nog veel gelijkvloerse kruisingen met verkeerslichten en uitritten van woningen aanwezig. Combinatie FLOOW gaat de weg inrichten als een stroomweg. Dat betekent dat de gelijkvloerse overgangen verdwijnen en het verkeer zo veilig met 100 km per uur over de weg kan rijden."

3.3 Method

The two main sources of evidence to collect data in the case study are the semi structured interview and a document analysis. The semi structured interview method is applied for two reasons. First to provide an initial representation of the projects and second to fill in the gaps when the provide documentation is not rigid enough to provide the complete and comprehensive overview of the SE application in the project. It is therefore possible that the audience is questioned twice.

In preparation for the semi-structured interview, some topics are already selected to be discussed in the interview. These are:

- The project characteristics;
- The extent of SE application;
- The relation between SBS, FBS, OBS & WBS;
- The ability of Reef Infra to coordinate successfully SE tasks.

To be able to anticipate the answers of the interviewee's, the semi-structured interview enables the interviewer to ask additional questions based on the answer of the interviewee. The interviewee's are project team members in the role of process manager or technical manager who were responsible for or to some extent involved in the application of SE. They are also the contact person who provide the documentation necessary for the document analysis.

Table 15: Data sources for unstructured interview.

Project	Interviewee	Role
Meppelerdiepsluis	Niek van Bentheim Erwin Nijmeijer	Projectleader Technical manager
A348	Peter Blom Koen Naafs	Process manager Process coordinator
Fietsroute Plus Haren	Martin Meijer Bert Lankheet	Technical manager Process coordinator
N34	Peter Blom Sander Kamphuis Gerben Vossebelt	Process manager Process coordinator Technical manager

It is important that the necessary documentation is comprehensive to be able to analyze fully the application of SE by Reef Infra. To ensure this an, overview of all the necessary documentation is created. This overview is presented in

Table 16: Data sources for document analysis.

Codering	*Documenten lijst*	*Doelstelling*
D.PI-1	Gunningsleidraad	Project informatie: Algemeen
D.PI-2	Vraagspecificatie 1 & 2	Project informatie: Eisen aan toepassing SE
D.PI-3	Project Management Plan	Project informatie: Aanpak project
D.PI-4	Ontwerpplan	Project informatie: Organisatie ontwerpproces
D.PI-5	Engineeringsplan	Project informatie: Organisatie technisch proces
D.SE-1	Eisenanalyse	Systems Engineering: Initiatie SE proces
S.SE-1	SBS	Systems Engineering: Decompositie systeem
S.SE-2	WBS	Systems Engineering: Decompositie systeem
D.SE-2	Verificatie & Validatie Plan Ontwerp	Systems Engineering: Organisatie Verificatie en Validatie
D.SE-3	Verificatie & Validatie Plan Realisatie	Systems Engineering: Organisatie Verificatie en Validatie
D.SE-4	Verificatierapport Oplevering	Systems Engineering: Resultaat Verificatie en Validatie
D.PI-6	Opleverdossier	Project informatie: Resultaat project
D.PI-7	Ontwerpnota's	Project informatie: Verloop ontwerpproces
D.PI-8	Actie- en besluitenlijst ontwerpoverleg	Project informatie: Verloop ontwerpproces
D.PI-9	Evaluaties van fasen (ontwerpfase/realisatiefase, etc.)	Project informatie: Verloop project

4 Data collection questions

4.1 Questions asked to the researcher

This part of the case study protocol describes the subjects and questions that are central in the semi-structured interviews. In this case study, these questions are asked to the researcher and not the interviewee's. This is according to the method of (Yin, 2014).

Table 17: Overview of the questions asked in individual cases.

Question
1. To which extend is SE applied in the project? Which tools were applied?
2. What was the maturity of applying SE in the project? Is SE applied with some confidence, or was there beforehand little experience with the application of SE?
3. To which extend is SE applied in a structured and standardized manner?
4. Why is SE applied in this project? What was its objective? Is SE applied to only verify contractual requirements?
5. How do the SBS, WBS, OBS and FA, and RA relate, follow or correlate to one another?
6. Was Reef Infra able to properly coordinate all of the SE activities in the project?
7. Is the project properly carried out? Properly in the sense of in time, to budget and as proposed beforehand during the tender phase.
8. Is the client satisfied with the execution of the project? Especially on the topic of: • Budget • Scheduling • Design process quality
9. Are you satisfied with the execution of the project? Did some of the aspects of the project not go as planned? Especially on the topic of: • Budget • Scheduling • Design process quality
10. What is in general your experience with the application of SE in the project?

5 Case study Report Guide

5.1 Introduction

5.2 Method

5.3 Questions for data collection

5.4 Summary Quick Scan Projects

5.5 Individual case report

5.5.1 Description of the case

5.5.2 Characteristics of the case

5.5.3 SE metrics & Project success metrics

3 Appendix – Case Study Report

1 Introduction

This case study report is the result of the case study part of the research project regarding the application of SE and how SE impacts project success in terms of budget performance, schedule performance and design process performance. We begin by describing the method. After which, we describe the questions for within-case and cross-case analyses. We end by stating some brief conclusions.

2 Method

This chapter is divided into: the document analysis (§2.1), the interviews (§2.2), the poster session (§2.3) and the data analysis pattern matching (§2.4).

2.1 Document analysis

The document analysis is part of the data gather strategy of the research. It is important that the necessary documentation is comprehensive to be able to analyze fully the application of SE by Reef Infra. To ensure this an, overview of all the necessary documentation is created. This overview is presented in Table 18.

Table 18: Overview list of necessary documentation to analyze the application of SE.

Codering	***Document list***	***Describtion***
D.PI-1	Gunningsleidraad	Project information: General
D.PI-2	Vraagspecificatie 1 & 2	Project information: Requirements SE
D.PI-3	Project Management Plan	Project information: Project organization
D.PI-4	Ontwerpplan	Project information: Design process organization
D.PI-5	Engineeringsplan	Project information: Technical process organization
S.SE-1	Eisenanalyse	Systems Engineering: Initiation SE process
S.SE-2	SBS	Systems Engineering: System decomposition
S.SE-3	WBS	Systems Engineering: System decomposition
D.SE-1	Verificatie & Validatie Plan	Systems Engineering: Verification and Validation process organization
D.SE-2	Verificatierapport	Systems Engineering: Verification and Validation results
D.PI-6	Opleverdossier	Project information: Project result
D.PI-7	Ontwerpnota's	Project information: Design process development
D.PI-8	Overall planning	Project information: Project development
D.PI-9	Termijnstaat	Project information: Project development

The document analysis is the main source of evidence for the case study. It provide both evidence for completion of the SE tasks as well as for applying the principles of SE in the projects. For example, when principle Traceability is taking into account Reef Infra must apply some numbering of requirements or specification of adjustments to documentation.

2.2 Interviews

The semi structured interview method is applied for two reasons. First to provide an initial representation of the projects and second to fill in the gaps when the provide documentation is not rigid enough to provide the complete and comprehensive overview of the SE application in the project. It is therefore possible that the audience is questioned twice. For every project, at least two interviews are conducted. The overview of the conducted interviews is presented below.

Table 19: Overview of the interviewees for each case.

Project	Interviewee	Role
Meppelerdiepsluis	Niek van Bentheim Erwin Nijmeijer	Projectleader Technical manager
A348	Peter Blom Koen Naafs	Process manager Process coordinator
Fietsroute Plus Haren	Martin Meijer Bert Lankheet	Technical manager Process coordinator
N34	Peter Blom Sander Kamphuis Gerben Vossebelt	Process manager Process coordinator Technical manager

In preparation for the semi-structured interview, some topics are already selected to be discussed in the interview. These are:

- The project characteristics;
- The extent of SE application;
- The relation between SBS, FBS, OBS & WBS;
- The ability of Reef Infra to coordinate successfully SE tasks;
- Project success in terms of budget performance, schedule performance and design process performance.

To be able to anticipate the answers of the interviewee's, the semi-structured interview enables the interviewer to ask additional questions based on the answer of the interviewee. The interviewee's are project team members in the role of process manager or technical manager who were responsible for or to some extent involved in the application of SE. They are also the contact person who provide the documentation necessary for the document analysis.

2.3 SE Poster Session

The idea of the poster session is that project employees can visualize the application of SE they have applied in the project. On account of the visualizations the project employees can share their experiences amongst the other projects so they can discuss the application of SE in practice. Solutions to common SE application challenges can be shared among employees of Reef Infra. In the end, the poster session provide input to improve the SE application of Reef Infra.

Overview participants

The project organization of the selected projects is analyzed to determine who is responsible for the application of SE in the projects. They are then invited to participate in the Poster session to come and elaborate on their view and experiences with the application of SE in their project. The overview is presented in Table 20.

Table 20: Poster session participants and their role in the projects.

Project	Participant	Job description
Meppelerdiepsluis	Niek van Bentheim Erwin Nijmeijer Sander Schooleman	Projectleider Werkvoorbereiding Procesbeheersing

N34	Peter Blom Sander Kamphuis Harry Steenbergen	Procesbeheersing Procescoördinator Procesmanager
Fietsroute Plus Haren	Martin Meijer Bert Lankheet	Werkvoorbereiding Procesbeheersing
Groene Loper (A2)	Mark Vlaanderen Gerben Vossebelt	Projectleider Projectcoördinatie
A348	Peter Blom	Procesbeheersing
Algemeen	Harry Steenbergen (SE deskundige Reef Infra) Renzo van Rijswijk (Domeinhoofd SE) Djim Witjes (Begeleiding onderzoek SE prestatie)	

2.4 Data analysis and pattern matching

The case study results are analyzed according to the pattern matching method of Yin (2014). To analyze the results of the case study we define the empirical patterns which are then compared to the theoretical patterns.

2.4.1 Theoretical patterns

The theoretical patterns consist of theoretical best practices regarding the application of SE in the Dutch Construction industry. Scientific literature is analyzed to develop a framework. This framework consist the best practices regarding the application of SE.

The framework which represent the theoretical best practices is presented below (Figure 13).

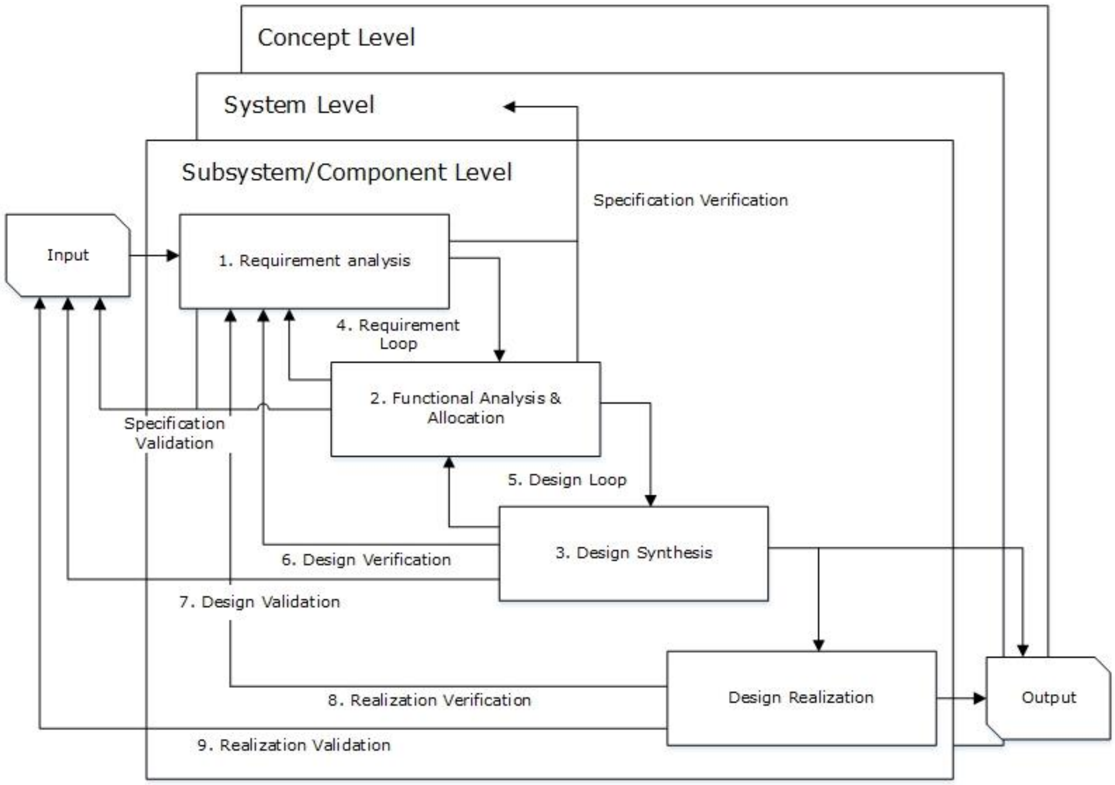

Figure 13: SE process framework with theoretical best practices.

2.4.2 Empirical patterns

The empirical patterns are case study findings concerning the SE application in the project. The empirical patterns are gathered as follows:

1. Determine SE specific Task application.
2. Determine project success characteristics in terms of budget performance, schedule performance and design quality performance.
3. Determine possible impact of SE application on project success characteristic.

We define the empirical patterns as follows:

The (specific steps) of the System Engineering (specific tasks) are completely/partially/not applied.

For example, the Requirement Breakdown Structure is output of the Requirement Analysis and therefore completely applied.

3 Questions for data collection

3.1 Questions for within-case analysis

Question
1. To which extend is SE applied in the project? Which tools were applied?
2. What was the maturity of applying SE in the project? Is SE applied with some confidence, or was there beforehand little experience with the application of SE?
3. To which extend is SE applied in a structured and standardized manner?
4. Why is SE applied in this project? What was its objective? Is SE applied to only verify contractual requirements?
5. How do the SBS, WBS, OBS and FA, and RA relate, follow or correlate to one another?
6. Was Reef Infra able to properly coordinate all of the SE activities in the project?
7. Is the project properly carried out? Properly in the sense of in time, to budget and as proposed beforehand during the tender phase.
8. Is the client satisfied with the execution of the project? Especially on the topic of: • Budget • Scheduling • Number of Request for Adjustments
9. Are you satisfied with the execution of the project? Did some of the aspects of the project not go as planned? Especially on the topic of: • Budget • Scheduling • Number of Request for Adjustments
10. What is in general your experience with the application of SE in the project?

3.2 Questions for cross-case analysis

Question
1. Do some projects score differently on specific SE tasks?
2. Do some projects score differently on SE sub-process (base process and feedback process)?
3. Do some projects score differently on the overall SE performance?
4. What was the impact of the SE application on budget performance in the project?
5. What was the impact of the SE application on schedule performance in the project?
6. What was the impact of the SE application the number of request for adjustments in the project?

4 Summary Quick Scan Projects

With the Quick scan we selected a total of four out of the possible six projects for the case study. The projects Meppelerdieplsuis, A348 and Fietsroute Plus Haren are a good representation of the portfolio of projects of Reef Infra. The combination of selected projects can provide a complete overview of the SE application of Reef Infra in their projects. The project N34 Witte Paal – Drentsche Grens will be used to verify and validate some of the findings because the project is yet to be delivered. However, a specific part of the project will be delivered early 2018 making this project suitable as test case.

Table 21: Quick scan results, overview of the case studies.

Project	Suitable as case study
Meppelerdiepsluis – Zwartsluis	Yes
A348	Yes
Fietsroute Plus Haren	Yes
N34 Witte Paal – Drentsche Grens	Yes, but only as test case
Groene Loper A2	No
Noorderbrug Maastricht	No
Fietstunnel Doetichem	No

5 Individual case report – Case MDS-WA

In this chapter, we describe the individual case report. In the reports we describe the characteristics of the case and the case specific SE metrics and BVP metrics. We end every report with a brief summary and initial within-case conclusions. The information in the reports are the results of the interviews and document analysis. If Relatics is used to structure the SE process, we complement these results with data present in Relatics. The results provide insights in how SE is applied and how successful the project was in terms of BVP objectives budget, schedule and design process quality performance.

5.1 Characteristics of the case

Characteristic	Description
Projectname	Meppelerdiepsluis
Client	Rijkswaterstaat
Contract Tenderprocedure	Elements of Engineering & Construct based on UAC-ic were used Best value Procurement
Client's expirience with SE	The client had a lot of experience with projects based on integrated contracts. The client was very experienced with SE.
Activities	Reef Infra had to realize a "klasse VA Schutsluis". They had to complete the following activities: • Realize new bridge; • Realize "Keersluishoofd"; • Realize "sluiskolk"; • Realize control building.
Involved disciplines	Hydraulic, steel and concrete engineering
Organization of the SE process	The SE process is organized within information management tool Relatics. The following aspects are put in the Relatics information model: • Requirement Analysis • Functional Analysis • SBS • WBS • Interface management • Verification • Risk analysis

5.2 SE metrics & Project success metrics

In this paragraph we present the SE metrics and BVP metrics as a result of the case study. First the SE performance project overview is presented to provide a complete picture of the SE performance in the case study. We continue by presenting the SE metrics and describing the evidence for the performance on individual SE-tasks. After this, we present the BVP objective metrics. We describe the evidence for the performance on individual BVP objectives. In both cases, the evidence consist of a summary of data sources and the within-case analysis.

5.2.1 Project overview

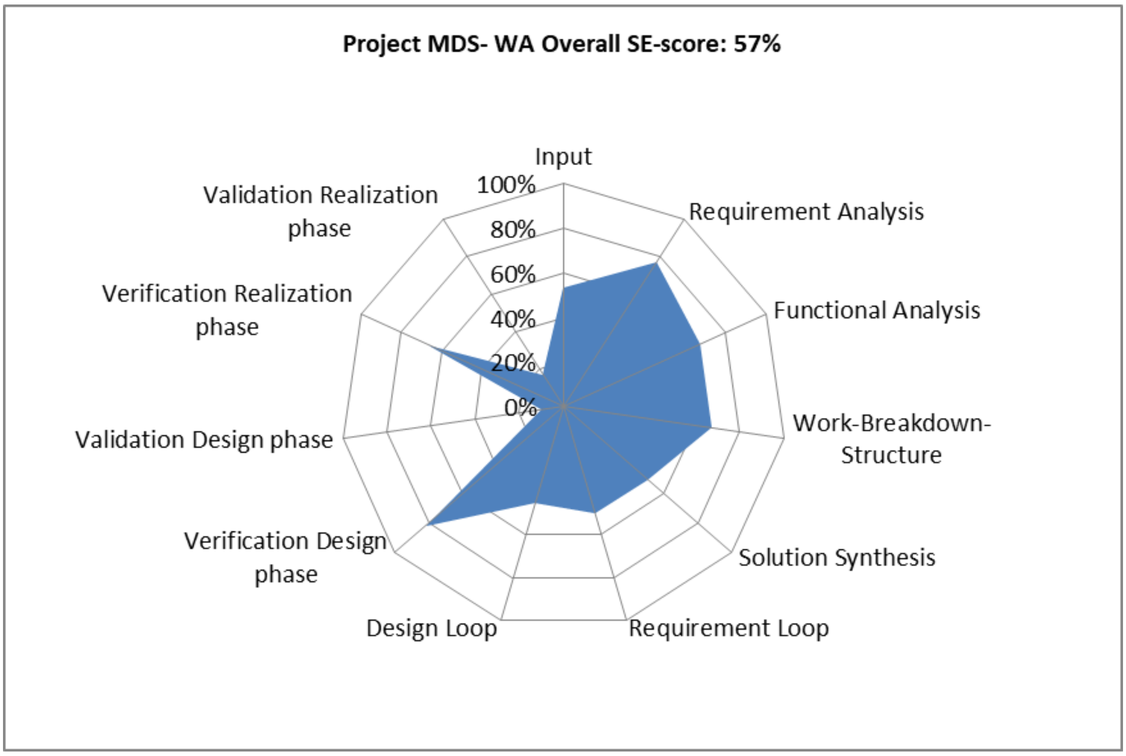

Figure 14: Overall SE-score Mepperlerdiepsluis.

5.2.2 SE metrics

First, we present an overview of the results of the SE performance measurement in the case study. After which we continue by presenting the evidence of the scores. The evidence consists of the data sources and the within-case analysis of every SE-tasks. The evidence is divided into three categories of performance:

1. what was done;
2. what was partially done;
3. what was not done.

Table 22: Overview scores individual SE tasks for case MDS-WA.

SE – task	Score [max 100%]
Input	54%
Requirement Analysis (RA)	77%
Functional Analysis (FA)	67%
Solution synthesis	50%
Output	75%

Requirement loop	50%
Design loop	45%
Verification Design phase	82%
Validation Design phase	10%
Verification Realization phase	67%
Validation Realization phase	17%
V-model	83%
Work-Breakdown-Structure (WBS)	63%
Overall SE	**57%**
Base process (RA, FA, WBS, Solution synthesis)	**66%**
Feedback process (Requirement loop, Design loop, Verific. Design, Valid. Design, Verific. Realization, Valid. Realization)	**45%**
Support process (V-model, Input, Output)	**71%**

Data sources

- Project documentation:
    - Contractdossier
        - Vraagspecificatie I
        - Vraagspecificatie II
        - Inschrijfleidraad
    - Project plans
        - Projectmanagementplan
        - Deelplan Kwaliteitsborging en Documentbeheer
        - Verificatie- en validatieplan
    - Verification en Validation:
        - Reports
        - Nota
    - Oplever- en/of restpuntenlijst
    - Termijnstaat
    - Schedule

- Interview #1 Niek van Bentheim
    - Location: Kantoor Reef Infra, te Oldenzaal
    - Duration: Duur
    - Job description: Projectleider (Ontwikkel- & Realisatiefase)
- Interview #2 Erwin Nijmeijer
    - Location: Kantoor Reef Infra, te Oldenzaal
    - Duration: Duur
    - Job description: Werkvoorbereider (Ontwikkel- & Realisatiefase)
- Systems Engineering Poster session
    - Kantoor Reef Infra, te Oldenzaal
    - 2,5 uur
    - Plenaire sessie

Within-case analysis

- Requirement Analysis (RA) (77%)
    - What was done:
    - What was done:
        - The following sources were used for the Requirement analysis
            - Specification Requirements *(Vraagspecificatie I)* and Specification Process *(Vraagspecificatie II)*
            - Tender documents Reef Infra *(documentatie aanbieding)*

            - Compulsory and informative documents *(Richtlijnen, standaarden, etc.)*
            - Stakeholder analysis
        - The Specification Requirements were analyzed case-by-case.
        - The output of the requirement analysis is the "Requirements Tree".
        - The structure of the Requirements Tree provided by the client was taken over.
        - The Requirements were formulated SMART.
        - The description of the Recruitments were formulated.
        - The sources of the Requirements were described.
        - Requirement numbering is applied to increase traceability.
        - Underlying or Upper lying requirements were described for every requirement.
        - Verification and validation plan was based on the RA.
        - Requirements types were allocated.

    - What was partially done:
        - Requirements were allocated to the SBS, but no evidence of it in the V&V-plan.
        - Requirements were allocated to the WBS, but no evidence of it in the V&V-plan.
        - The requirements were allocated to related activities, but no evidence of it in the V&V-plan.

    - What was not done:
        - The "Who-reads-What list" was not applied to ensure that all available documentation is analyzed on additional requirements.
        - Requirements were not integral analyzed by the project team.
        - The structure of the Requirements Tree provided by the Client was not checked for "fit-for-purpose".
        - The client requirement specifications were not made.
        - The level of detail for the requirements were not allocated.

- Functional Analysis (67%)
    - What was done:
        - The functional analysis was done in Relatics.
        - The output of the Functional Analysis is the FBS.
        - The FBS is structured as a functions tree.
        - Functions are numbered to support demonstrability.
        - The output of the Functional Analysis is the System Breakdown Structure.
        - The SBS is structured as an objects tree.
        - Objects are numbered to support demonstrability.
        - The Object specifications consist of:
            - Underlying and Upper lying objects;
            - Object type;
            - Functions;
            - Design activities;
            - Execution activities;
            - Interfaces;
            - Risks.
        - The Object-requirement specification was made, therefore objects are linked to requirements.

    - What was partially done:

        - The correct formulation of the combination of a noun and a verb is used in the description of the function, but not in all function descriptions.
        - Adjustments to the V&V plan are recorded, however the reasoning behind the adjustments is not.

    - What was not done;
        - The Functional Breakdown Structure was not linked to RBS.

- Work-Breakdown-Structure (63%)
    - What was done:
        - The Work Breakdown Structure was made in Relatics and linked to the Requirement Breakdown Structure.
        - The WBS was revised based on the Requirement Analysis.
        - The output of the WBS is the activities tree.
        - Activity - Requirements specifications were made.

    - What was partially done:
        - Activity – objects specifications were made (WP Objectplan). The following items were not specified in the Activity – Objects specifications:
            - Budget;
            - Schedule, only the reference;
            - Result of the activities.

    - Wat was not done:
        - The WBS is not revised based on the Functional Analysis.
        - Activity specifications were not made in Relatics.
        - The WBS is not revised based on the Solution Synthesis.

- Solution Synthesis (50%)
    - What was done:
        - Design solutions were based on the RBS.
        - Design solutions were based on object specifications.

    - What was partially done:
        - Design decisions can be partially traced back to RBS/FBS/SBS.
        - Design solutions were developed simultaneously with the Requirement Analysis and Functional Analysis were finalized.
        - The Definitive Design is finalized simultaneously when the V&V plan was accepted by the Client.

    - Wat was not done:
        - None

- Requirement loop (50%)
    - What was done:
        - None

    - What was partially done:
        - The RBS is partially revised based on the functional analysis. The RBS is only linked to the SBS not the FBS.
        - The RBS is revised on fixed moments, not continuous.
        - Adjustments to the RBS were recorded but the reasoning behind the adjustments not.

    - Wat was not done:

        - None

- Design loop (45%)
    - What was done:
        - The V&V plan was adjusted based on Design Solution Synthesis.

    - What was partially done:
        - The RBS was partially adjusted based on Design Solution Synthesis, but the reasoning behind was not.
        - Adjustments to the RBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the FBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the SBS were recorded demonstrable, but the reasoning behind was not.
        - Object specifications were partially adjusted based on Design Solution Synthesis.
        - Adjustments to the V&V plan were recorded demonstrable, but the reasoning behind was not.

    - Wat was not done:
        - The FBS was not adjusted based on Design Solution Synthesis.
        - Adjustments to the SBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the Object Specifications and the reasoning behind were not recorded demonstrable.

- Verification design phase (82%)
    - What was done:
        - Verification in the design phase is executing according to the V&V plan.
        - The following items were mentioned in the Verification plan Design Phase:
            - Requirement code;
            - Requirement description;
            - Underlying Requirements;
            - Upper lying Requirements;
            - Verification method;
            - Allocation to OBS;
            - Documents for evidence;
            - Verification moment;
            - Link to WBS;
            - Verification result;
        - Verification was done on multiple abstraction levels.
        - Underlying Requirements and Objects and Upper lying Requirements and Objects were verified by making the connection.
        - The Verification report with evidence was made.
        - Adjustments to documentation was made when the verification results were not positive.

    - What was partially done:
        - Underlying Functions and Upper lying Functions were not verified by making the connection, because this connection was not stated.
        - Second verifications were just on one abstraction level.

    - Wat was not done:

        - Adjustments to documentation caused by negative verification results were not recorded demonstrable.

- Validation design phase (10%)
    - What was done:

    - What was partially done:
        - None

    - Wat was not done:
        - No specific Validation was executed.
        - There is no specific validation report.
        - Reasoning behind the adjustment to documentation was not recorded demonstrable.

- Verification realization phase (67%)
    - What was done:
        - Verification was done by inspection.
        - Verification was done to the first abstraction level.
        - The project team used the Verification plan to execute the Verification activities.
        - Verification report with evidence was made.
        - Document verification was executed.

    - What was partially done:
        - Verification was done also to other abstraction levels, but only to one more level.
        - Adjustments to documentation was recorded demonstrable, however reasoning behind the adjustment was not.

    - Wat was not done:
        - The realized design solutions were not checked to see if these fulfill the functions.

- Validation realization phase (17%)
    - What was done:
        - None

    - What was partially done:
        - Adjustments to documentation was recorded demonstrable, however reasoning behind the adjustment was not.

    - Wat was not done:
        - During the realization phase no validation was executed.
    -
- V-model (83%)
    - What was done:
        - Decomposition of the requirements, functions and objects was made in Relatics.
        - Specification and solution phase are connected by Objects – Requirements Specifications.

    - What was partially done:
        - The disaggregation of design solutions was partly done, little evidence can be found.

- Wat was not done:
  - None

5.2.3 Project success metrics

The project success metrics for the case study are presented in Table 8. The metrics comprise project success characteristics in terms of Budget performance, Schedule performance and Design process quality.

Table 23: Overview of the Project success metrics.

Project success indicators	Score
Budget Performance	1.85
Schedule Performance	1.46
Design process quality	
• # versions DO	
• # versions UO	5
• # versions Ontwerpnota	4
• # opleverpunten/restpunten	
• # afwijkingen	183
• # VTW's	45

The project success metrics are divided into Budget performance, Schedule performance and Design process quality.

The Budget performance is calculated as followed:

Budget Performance = Actual budget spent / Planned budget

The Schedule performance is calculated as followed:

Schedule Performance = Actual schedule / Planned schedule

These calculations provide factors to be able to compare project results. When the factor is close to zero, then the actual budget and schedule is the same as the planned budget and schedule. The Budget performance factor is 1.85. The actual budget spent is 85% larger than the planned budget spent. The schedule performance factor is 1.46. With incorporating the Requests for Adjustments and Deviations, the project was delivered late.

During the project there were financial issues with subcontractors. An important partner went bankrupt, causing much delay. Moreover, Reef Infra invested allot in the SE process. This made the SE process bulky. There was little overview over the SE process because too much information was gathered and Reef Infra tried to structure it all in Relatics. An extensive list of requirements was derived and had to be linked to an extensive list of objects and activities. Moreover, this was one of the first large projects in which Reef Infra applied SE. Some SE best practices were incorporated. Overall, the project team lacked experience with SE in complex projects.

6 Individual case report – Case A348 -BE

In this chapter, we describe the individual case reports. In the reports we describe the description of the case, the characteristics of the case and the case specific SE metrics and BVP metrics. We end every report with a brief summary and initial within-case conclusions. The information in the reports are the results of the interviews and document analysis. If Relatics is used to structure the SE process, we complement these results with data present in Relatics. The results provide insights in how SE is applied and how successful the project was in terms of BVP objectives budget, schedule and design process quality performance.

6.1 Characteristics of the case

Characteristic	Description
Projectname	Vervangen bruggen, perceel A348
Client	Provincie Gelderland
Contract Tenderprocedure	Design & Construct based on UAC-ic EMVI
Client's expirience with SE	The client had some experience with projects with an integrated contract like Design & Construct. Also, the client has mediocre experience with SE.
Activities	Reef Infra had to realize two flyovers called Overhagen and Biljoen. They had to complete the following activities: • Design, realize and maintain new flyovers; • Design, realize and maintain new road construction; • Design, realize and maintain new noise reduction walls.
Involved disciplines	Mainly road construction and concrete engineering.
Organization of the SE process	The SE process is organized within information management tool Relatics. The following aspects are organized in the Relatics information model: • Requirement Analysis • SBS • WBS • OBS • Verification • Document management • Risk analysis • Interface management • Hazard register • VTW's (Request for adjustments)

6.2 SE metrics & Project success metrics

In this paragraph we present the SE metrics and BVP metrics as a result of the case study. First the SE performance project overview is presented to provide a complete picture of the SE performance in the case study. We continue by presenting the SE metrics and describing the evidence for the performance on individual SE-tasks. After this, we present the BVP objective metrics. We describe the evidence for the performance on individual BVP objectives. In both cases, the evidence consist of a summary of data sources and the within-case analysis.

6.2.1 Project overview

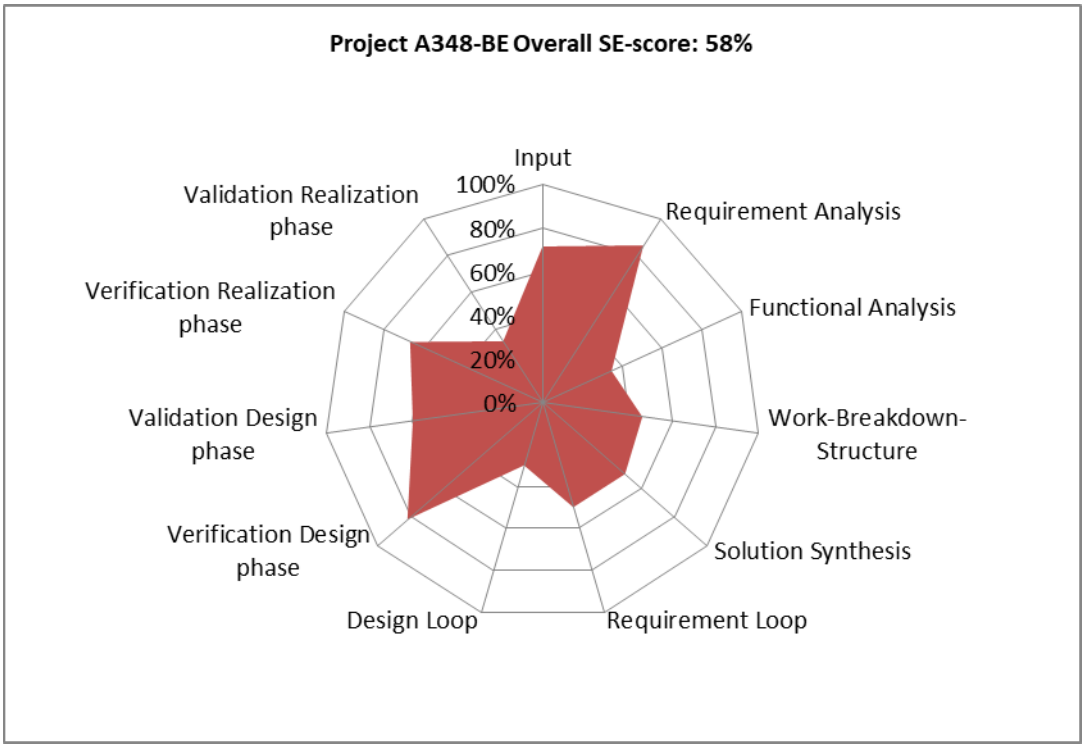

Figure 15: Overview SE-score A348.

6.2.2 SE metrics

First, we present an overview of the results of the SE performance measurement in the case study. After which we continue by presenting the evidence of the scores. The evidence consists of the data sources and the within-case analysis of every SE-tasks. The evidence is divided into three categories of performance:

4. what was done;
5. what was partially done;
6. what was not done.

Table 24: Overview scores individual SE tasks for case MDS-WA.

SE – task	Score [max 100%]
Input	71%
Requirement Analysis (RA)	85%
Functional Analysis (FA)	35%
Solution synthesis	50%
Output	75%
Requirement loop	50%
Design loop	30%
Verification Design phase	82%
Validation Design phase	60%
Verification Realization phase	67%
Validation Realization phase	33%
V-model	67%
Work-Breakdown-Structure (WBS)	46%
Overall SE	**58%**
Base process (RA, FA, WBS, Solution synthesis)	**54%**
Feedback process (Requirement loop, Design loop, Verific. Design, Valid. Design, Verific. Realization, Valid. Realization)	**54%**
Support process (V-model, Input, Output)	**71%**

Data sources

- Project documentation:
    - Contractdossier
        - Vraagspecificatie I
        - Inschrijfleidraad
    - Project plans
        - Projectmanagementplan
        - Engineeringsplan
        - Verificatie- en validatieplan Ontwerp fase
        - Verificatie- en validatieplan Realisatie fase
    - Ontwerp
        - Ontwerpnota Definitief Ontwerp
        - Ontwerpnota Uitvoeringsontwerp
    - Verification en Validation:
        - Reports
        - Nota
    - Oplever- en/of restpuntenlijst
    - Termijnstaat
    - Schedule

- Interview #1 Peter Blom
    - Location: Kantoor Reef Infra, te Oldenzaal
    - Duration: 1 hour and 15 minutes
    - Job description: Procesbeheersing (Ontwikkel- & Realisatiefase)
- Interview #2 Koen Naafs
    - Location: Kantoor Reef Infra, te Oldenzaal
    - Duration: 50 minutes
    - Job description: Werkvoorbereider/procesbeheersing (Ontwikkel- & Realisatiefase)
- Systems Engineering Poster session
    - Kantoor Reef Infra, te Oldenzaal
    - 2,5 uur

- Plenaire sessie

Within-case analysis

- Requirement Analysis (RA) (85%)
  - What was done:
    - The following sources were used for the Requirement analysis
      - Specification Requirements *(Vraagspecificatie I)* and Specification Process *(Vraagspecificatie II)*
      - Tender documents Reef Infra *(documentatie aanbieding)*
      - Compulsory and informative documents *(Richtlijnen, standaarden, etc.)*
      - Stakeholder analysis
    - The Specification Requirements were analyzed case-by-case.
    - The "Who-reads-What list" ensured that all available documentation is analyzed on additional requirements.
    - Requirements were integral analyzed by the project team.
    - The output of the requirement analysis is the "Requirements Tree".
    - The structure of the Requirements Tree provided by the client was taken over.
    - The Requirements were formulated SMART.
    - The description of the Recruitments were formulated.
    - The sources of the Requirements were described.
    - Requirement numbering is applied to increase traceability.
    - Verification and validation plan was based on the RA.
    - Requirements were allocated to the SBS.
    - Requirements were allocated to the WBS.
    - Requirements types were allocated.

  - What was partially done:
    - Underlying or Upper lying requirements were not described for every requirement.

  - What was not done:
    - The structure of the Requirements Tree provided by the Client was not checked for "fit-for-purpose".
    - The client requirement specifications were not made.
    - The level of detail for the requirements were not allocated.
    - The requirements were not allocated to related activities.

- Functional Analysis (35%)
  - What was done:
    - The output of the FA was the SBS.
    - The SBS is structured as an Objects tree.
    - Objects are numbered to support demonstrability.
    - The Object-requirement specification was made, therefore objects are linked to requirements.
    - The SBS was link to the RBS

  - What was partially done:
    - The V&V plan was adjusted based on the SBS and WBS but not based on the FBS and Object Specifications.
    - Adjustments to the V&V plan are recorded, however the reasoning behind the adjustments is not.

  - What was not done;
    - The output of the FA was not the FBS.
    - The FBS is not structured as a functions tree.
    - The correct formulation of the combination of a noun and a verb was not used in the description of the function.
    - Functions were not numbered to support demonstrability.
    - The FBS was not linked to RBS, SBS and WBS.
    - The WBS was not linked to the SBS.
    - There are no Object specifications.

- Work-Breakdown-Structure (46%)
  - What was done:
    - The WBS was made in Relatics and linked to the RBS.
    - The WBS was revised based on the RA.
    - The output of the WBS is the Activities tree.
    - Activity - Requirements specifications were made.
  - What was partially done:
    - None
  - Wat was not done:
    - The WBS is not revised based on the Functional Analysis.
    - Input for the Activity was not allocated.
    - Output for the Activity was not allocated.
    - Activity specifications were not made in Relatics.
    - The WBS is not revised based on the Solution Synthesis.

- Solution Synthesis (50%)
  - What was done:
    - Design solutions were based on the RBS.
    - Design solutions were developed after the Requirement Analysis.
  - What was partially done:
    - None
  - Wat was not done:
    - Design solutions were not based on object specifications.
    - Design solutions were not based on FBS.

- Requirement loop (50%)
  - What was done:
    - None
  - What was partially done:
    - Adjustments to the RBS were recorded but the reasoning behind the adjustments not.
  - Wat was not done:
    - The RBS is not revised based on the functional analysis. The RBS is only linked to the SBS not the FBS.

- Design loop (30%)
  - What was done:
    - The V&V plan was adjusted based on Design Solution Synthesis.
    - The RBS was adjusted based on Design Solution Synthesis.

- What was partially done:
  - Adjustments to the RBS were recorded demonstrable, but the reasoning behind was not.
  - Adjustments to the SBS were recorded demonstrable, but the reasoning behind was not.
  - Adjustments to the V&V plan were recorded demonstrable, but the reasoning behind was not.

- Wat was not done:
  - The FBS was not adjusted based on Design Solution Synthesis.
  - Adjustments to the FBS were not recorded demonstrable.
  - Object specifications were not adjusted based on Design Solution Synthesis.
  - Adjustments to the Object Specifications and the reasoning behind were not recorded demonstrable.

- Verification design phase (82%)
  - What was done:
    - Verification in the design phase is executing according to the V&V plan.
    - The following items were mentioned in the V&V plan Design Phase:
      - Requirement code;
      - Requirement description;
      - Verification method;
      - Verification moment;
      - Allocation to OBS;
      - Documents for evidence.
    - Verification was done on multiple abstraction levels.
    - The Verification report with evidence was made.
    - Adjustments to documentation was made when the verification results were not positive.

  - What was partially done:
    - None

  - Wat was not done:
    - The following items were not mentioned in the V&V plan Design Phase:
      - Underlying Requirements;
      - Upper lying Requirements;
      - Activity number, to link the verification to the corresponding activities;
    - Adjustments to documentation caused by negative verification results were not recorded demonstrable.
    - Underlying Requirements and Objects and Upper lying Requirements and Objects were not verified by making the connections between those.

- Validation design phase (60%)
  - What was done:
    - During the design phase validation was done to the first abstraction level (Validatie ontwerp overleg met Opdrachtgever).
    - Based on the Validations, adjustments to documentation was made.

  - What was partially done:
    - None

  - Wat was not done:
    - There is no specific validation report or specific validation results in the Validation and Verification Report.
    - Reasoning behind the adjustment to documentation was not recorded demonstrable.

- Verification realization phase (67%)
  - What was done:
    - Verification was done by inspection.
    - Verification was done to the first abstraction level.
    - Verification was done also to other abstraction levels.
    - The project team used the V&V plan to execute the Verification activities.
    - Verification report with evidence was made.
    - Document verification was executed.
  - What was partially done:
    - Adjustments to documentation was recorded demonstrable, however reasoning behind the adjustment was not.
  - Wat was not done:
    - The realized design solutions were not checked to see if these fulfill the functions.

- Validation realization phase (33%)
  - What was done:
    - None
  - What was partially done:
    - Adjustments to documentation was recorded demonstrable, however reasoning behind the adjustment was not.
  - Wat was not done:
    - During the realization phase no validation was executed.
    - The Validation report with evidence was not made.
    - Adjustments to documentation was made, but reasons for adjustments cannot be traced back to validation results.

- V-model (67%)
  - What was done:
    - None
  - What was partially done:
    - Decomposition of the requirements and objects was made in Relatics. There was no decomposition of functions.
    - The disaggregation of design solutions was partly done, little evidence can be found.
    - Specification and solution phase are connected by verification, but not by Object – Requirement Specifications.
  - Wat was not done:
    - None

6.2.3 Project success metrics

The project success metrics for the case study are presented in Table 8. The metrics comprise project success characteristics in terms of Budget performance, Schedule performance and Design process quality.

Table 25: Overview of the Project success metrics.

Project success indicators	Score
Budget Performance	1.19
Schedule Performance	1.42
Design process quality	
• # versions DO	3
• # versions UO	4
• # versions Ontwerpnota	1
• # opleverpunten/restpunten	27
• # afwijkingen	67
• # VTW's	26

The project sucess metrics are divided into Budget performance, Schedule performance and Design process quality.

The Budget performance is calculated as followed:

Budget Performance = Actual budget spent / Planned budget

The Schedule performance is calculated as followed:

Schedule Performance = Actual schedule / Planned schedule

These calculations provide factors to be able to compare project results. When the factor is close to zero, then the actual budget and schedule is the same as the planned budget and schedule. The Budget performance factor is 1.19. The actual budget spent is 19% larger than the planned budget spent. The schedule performance factor is 1.42. With incorporating the Requests for Adjustments and Deviations, the project was delivered late.

We should consider that the project was initially handed to another contracting firm. However, this firm had to hand in the project because in judicial procedures it was established that the firm did not meet necessary qualifications. The project was then handed to Reef Infra. This was six months after initial tender. Therefore Reef Infra had to redo their initial bid because i.e. prices of building materials had changed. Reef Infra took time to redo their initial bid to analyze project risks and incorporate these in an updated schedule and budget. The second schedule was 42% longer than the initial schedule. If Reef Infra had won the initial tender, then they probably would have delivered the project with 42% delay. If we only take the new situation into account, that the project started after it was handed to Reef Infra, then the budget performance is different. The project was eventually delivered according to the second schedule, in that case the schedule performance factor is 1.0.

7 Individual case report – Case FPH-WE

In this chapter, we describe the individual case reports. In the reports we describe the description of the case, the characteristics of the case and the case specific SE metrics and BVP metrics. We end every report with a brief summary and initial within-case conclusions. The information in the reports are the results of the interviews and document analysis. If Relatics is used to structure the SE process, we complement these results with data present in Relatics. The results provide insights in how SE is applied and how successful the project was in terms of BVP objectives budget, schedule and design process quality performance.

7.1 Characteristics of the case

Characteristic	Description
Projectname	Fietsroute Plus Haren
Client	Gemeente Haren
Contract Tenderprocedure	Engineering & Construct based on UAC-ic Best value Procurement
Client's expirience with SE	The client had not previously used the BVP tender procedure. Moreover, the client had also little experience with projects with an integrated contract like Engineering & Construct.
Activities	Reef Infra had to realize a premium cycle connection between Haren and Groningen. They had to complete the following activities: • Realize a cycling path; • Realize a roundabout; • Upgrade sewage system on specific locations; • Organize design requirements and develop preliminary design, definite design and execution design; • Realize temporary road signs; • Decompose redundant objects; • Communication with stakeholders; • Coordination of subcontractors.
Involved disciplines	Mainly road construction
Organization of the SE process	The SE process is organized within information management tool Relatics. However, during the project Relatics became too challenging for the subcontractor responsible for the design. Reef Infra had to switch to Excel for its SE process. The following aspects are organized in the Relatics information model: • Requirement analysis • Functional analysis • SBS

	• OBS • WBS • Document management

7.2 SE metrics & Project sucess metrics

In this paragraph we present the SE metrics and BVP metrics as a result of the case study. First the SE performance project overview is presented to provide a complete picture of the SE performance in the case study. We continue by presenting the SE metrics and describing the evidence for the performance on individual SE-tasks. After this, we present the BVP objective metrics. We describe the evidence for the performance on individual BVP objectives. In both cases, the evidence consist of a summary of data sources and the within-case analysis.

7.2.1 Project overview

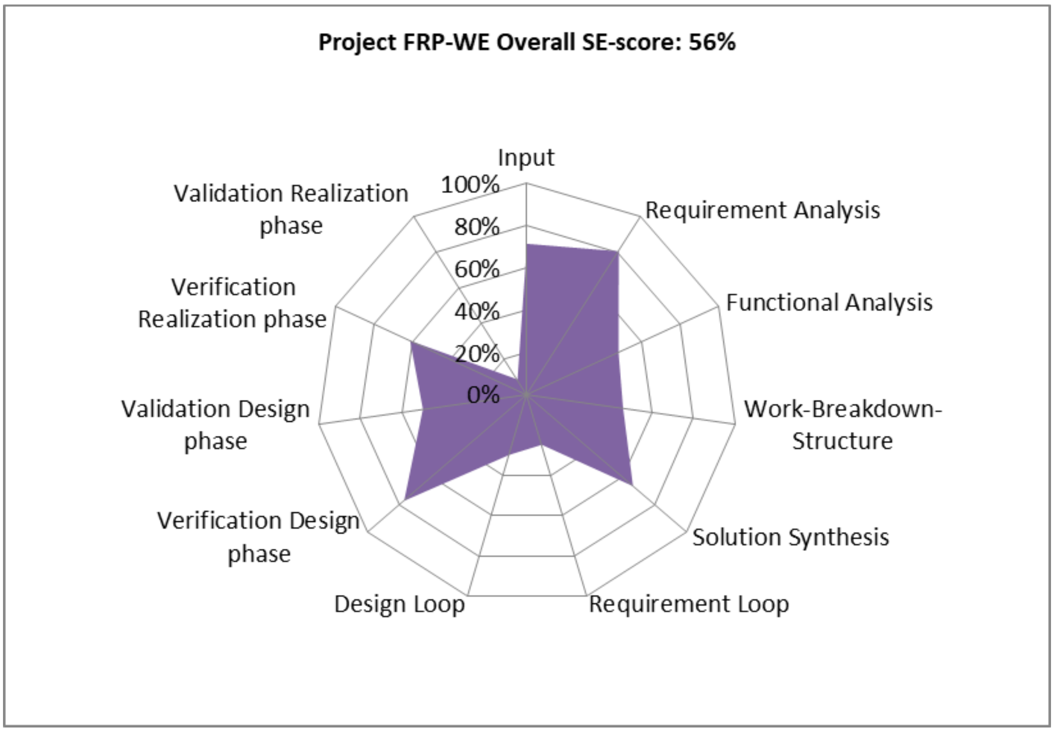

Figure 16: Overview SE-score Fietsroute Plus Haren.

7.2.2 SE metrics

First, we present an overview of the results of the SE performance measurement in the case study. After which we continue by presenting the evidence of the scores. The evidence consists of the data sources and the within-case analysis of every SE-tasks. The evidence is divided into three categories of performance:

7. what was done;
8. what was partially done;
9. what was not done.

Table 26: Overview scores individual SE tasks for case MDS-WA.

SE – task	Score [max 100%]
Input	71%
Requirement Analysis (RA)	81%
Functional Analysis (FA)	48%
Solution synthesis	67%
Output	75%
Requirement loop	25%
Design loop	30%
Verification Design phase	77%
Validation Design phase	50%
Verification Realization phase	61%
Validation Realization phase	8%
V-model	83%
Work-Breakdown-Structure (WBS)	46%
Overall SE	**56%**
Base process (RA, FA, WBS, Solution synthesis)	**60%**
Feedback process (Requirement loop, Design loop, Verific. Design, Valid. Design, Verific. Realization, Valid. Realization)	**42%**
Support process (V-model, Input, Output)	**77%**

Data sources

- Project documentation:
    - Contractdossier
        - Vraagspecificatie I
        - Inschrijfleidraad
    - Project plans
        - Projectmanagementplan
        - Engineeringsplan
        - Verificatie- en validatieplan Ontwerp fase
        - Verificatie- en validatieplan Realisatie fase
    - Design
        - Ontwerpnota Definitief Ontwerp
        - Ontwerpnota Uitvoeringsontwerp
        - Notulen Overleggen
    - Verification en Validation:
        - Reports
        - Nota
    - Oplever- en/of restpuntenlijst
    - Termijnstaat
    - Schedule

- Interview #1 Bert Lankheet
    - Location: Kantoor Reef Infra, te Oldenzaal
    - Duration: 1 hour and 20 minutes
    - Job description: Procesmanager (Ontwikkel- & Realisatiefase)
- Interview #2 Martin Meijer
    - Location: Kantoor Reef Infra, te Oldenzaal
    - Duration: 1 hour and 20 minutes
    - Job description: Werkvoorbereider (Ontwikkel- & Realisatiefase)
- Systems Engineering Poster session
    - Kantoor Reef Infra, te Oldenzaal
    - 2,5 uur

- Plenaire sessie

Within-case analysis

- Requirement Analysis (RA) (81%)
  - What was done:
    - The following sources were used for the Requirement analysis
      - Vraagspecificaties
      - Aanbieding Reef Infra
      - Bindende en informatieve documenten
      - Stakeholder analysis
    - Additionally, stakeholders were asked to review the provisional design to extend the RA.
    - The output of the requirement analysis is the "Requirements Tree".
    - The Requirements were formulated SMART.
    - The description of the Reqruiments were made.
    - Requirements types were allocated.
    - Subordinate requirements were derived.
    - The sources of the Requirements were described.
    - Requirement numbering is applied to increase traceability.
    - Verification and validation plan was based on the RA.

  - What was partially done:
    - Requirements allocation was partially done. The Requirement were allocated to the SBS but not the WBS.

  - What was not done:
    - Client's Requirement structurer was not checked for "fit-for-purpose".
    - The client requirement specifications were not made.
    - The level of detail for the requirements were not allocated.
    - The related activities were not allocated to the Requirements.

- Functional Analysis (48%)
  - What was done:
    - The functional analysis was done in Relatics.
    - The output of the Functional Analysis is the Functional Breakdown Structure.
    - The FBS is structured as a functions tree.
    - The correct formulation of the combination of a noun and a verb is used in the description of the function.
    - Functions are numbered to support demonstrability.
    - The output of the Functional Analysis is the System Breakdown Structure.
    - The SBS is structured as an objects tree.
    - Objects are numbered to support demonstrability.
    - The Object-requirement specification was made, therefore objects are linked to requirements.
    - The SBS was linked to WBS.

  - What was partially done:
    - The V&V plan was adjusted based on the SBS and WBS but not based on the FBS and Object Specifications.
    - Adjustments to the V&V plan are recorded, however the reasoning behind the adjustments is not.

  - What was not done;

    - The FBS was not linked to RBS, SBS and WBS.
    - The Work Breakdown Structure was not linked to the System Breakdown Structure.
    - There are no Object specifications.

- Work-Breakdown-Structure (46%)
  - What was done:
    - The Work Breakdown Structure was made in Relatics and linked to the Requirement Breakdown Structure.
    - The WBS was revised based on the Requirement Analysis.
    - The output of the WBS is the activities tree.
    - Activity - Requirements specifications were made.
    - Activity specifications were made in Excel/Word and combined in an overall Work plan (Werkplan realisatiefase).

  - What was partially done:
    - Activity – objects specifications were made (Werkplan realisatiefase). The following items were not specified in the Activity – Objects specifications:
      - Budget;
      - Schedule;
      - Interfaces with other Activity – Objects specifications;
      - Result of the activity.
    - The risks allocated to activities are described in the WBS, however these are only safety related.

  - Wat was not done:
    - The WBS is not revised based on the FBS.
    - Activity specifications were not made in Relatics.
    - The WBS is not revised based on the Solution Synthesis.

- Solution Synthesis (67%)
  - What was done:
    - Design solutions were based on the RBS.
    - Design solutions were developed after the Requirement Analysis and Functional Analysis were finalized.
    - The Definitive Design is finalized after the V&V plan was accepted by the Client.
  - What was partially done:
    - None
  - Wat was not done:
    - Design solutions were not based on object specifications.

- Requirement loop (25%)
  - What was done:
    - None

  - What was partially done:
    - The RBS is partially revised based on the functional analysis. The RBS is only linked to the SBS not the FBS.
    - The RBS is revised on fixed moments, not continuous.
    - Adjustments to the RBS were recorded but the reasoning behind the adjustments not.

  - Wat was not done:

        - None

- Design loop (30%)
    - What was done:
        - The V&V plan was adjusted based on Design Solution Synthesis.
        - The RBS was adjusted based on Design Solution Synthesis.

    - What was partially done:
        - Adjustments to the RBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the FBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the SBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the V&V plan were recorded demonstrable, but the reasoning behind was not.

    - Wat was not done:
        - The FBS was not adjusted based on Design Solution Synthesis.
        - Adjustments to the SBS were recorded demonstrable, but the reasoning behind was not.
        - Object specifications were not adjusted based on Design Solution Synthesis.
        - Adjustments to the Object Specifications and the reasoning behind were not recorded demonstrable.

- Verification design phase (77%)
    - What was done:
        - Verification in the design phase is executing according to the V&V plan.
        - The following items were mentioned in the V&V plan Design Phase:
            - Requirement code;
            - Requirement description;
            - Underlying Requirements;
            - Upper lying Requirements;
            - Verification method;
            - Allocation to OBS;
            - Documents for evidence.
        - Verification was done on multiple abstraction levels.
        - Underlying Requirements and Objects and Upper lying Requirements and Objects were verified by making the connection.
        - The Verification report with evidence was made.
        - Adjustments to documentation was made when the verification results were not positive.

    - What was partially done:
        - Underlying Functions and Upper lying Functions were not verified by making the connection, because this connection was not stated.

    - Wat was not done:
        - The following items were not mentioned in the V&V plan Design Phase:
            - Verification moment;
            - Activity number, to link the verification to the corresponding activities;

        - Adjustments to documentation caused by negative verification results were not recorded demonstrable.

- Validation design phase (50%)
    - What was done:
        - During the design phase validation was done to the first abstraction level (Validatie ontwerp overleg met Opdrachtgever).
        - During the design phase validation was done to the second abstraction level (Validatie ontwerp presentative met Omwonenden).
        - Based on the Validations, adjustments to documentation was made.

    - What was partially done:
        - None

    - Wat was not done:
        - There is no specific validation report.
        - Reasoning behind the adjustment to documentation was not recorded demonstrable.

- Verification realization phase (61%)
    - What was done:
        - Verification was done by inspection.
        - Verification was done to the first abstraction level.
        - Verification was done also to other abstraction levels.
        - The project team used the V&V plan to execute the Verification activities.
        - Verification report with evidence was made.
        - Document verification was executed.

    - What was partially done:
        - After verification and when verification result was negative, not all documentation was adjusted as some verification results were not properly administered.
        - Adjustments to documentation was recorded demonstrable, however reasoning behind the adjustment was not.

    - Wat was not done:
        - The realized design solutions were not checked to see if these fulfill the functions.

- Validation realization phase (8%)
    - What was done:
        - None

    - What was partially done:
        - None

    - Wat was not done:
        - During the realization phase no validation was executed.
    -
- V-model (83%)
    - What was done:
        - Decomposition of the requirements, functions and objects was made in Relatics.
        - Specification and solution phase are connected by Objects – Requirements Specifications.

- What was partially done:
  - The disaggregation of design solutions was partly done, little evidence can be found.

- Wat was not done:
  - None

7.2.3 Project success metrics

The project success metrics for the case study are presented in Table 8. The metrics comprise project success characteristics in terms of Budget performance, Schedule performance and Design process quality.

Table 27: Overview of the Project Success metrics.

Project success indicators	Score
Budget Performance	1.17
Schedule Performance	1.03
Design process quality	
• # versions DO	0
• # versions UO	4
• # versions Ontwerpnota	3
• # opleverpunten/restpunten	85
• # afwijkingen	21
• # VTW's	16

The project success metrics are divided into Budget performance, Schedule performance and Design process quality.

The Budget performance is calculated as followed:

Budget Performance = Actual budget spent / Planned budget

The Schedule performance is calculated as followed:

Schedule Performance = Actual schedule / Planned schedule

These calculations provide factors to be able to compare project results. When the factor is close to zero, then the actual budget and schedule is the same as the planned budget and schedule. The Budget performance factor is 1.17. The actual budget spent is 17% larger than the planned budget spent. The schedule performance factor is 1.03. With incorporating the Requests for Adjustments and Deviations, the project was delivered to the planned schedule.

Looking at the project characteristics and the tender procedure, the project was straightforward and the tender procedure was intensive. This assures proper understanding of the project, great investment in the SE process and therefore a successful project in terms of budget and schedule performance. However, after great investment in the SE process the organization of it was not in correspondence to the level of difficulty of the project (due to it straightforward character). The investment in the SE process was downsized. The downsizing was affecting initially the feedback process of the SE process, hence the low score of X%. The RA, FA and SBS were developed in

Relatics, however the link between these were not incorporated in the information model. This hampered the feedback processes, because documentation had to be made manually. There were no Objects specifications, and only the Work Breakdown Structure was put in Relatics. The Activity Specifications were derived manually, making the feedback process less likely to incorporate these Specification documentations.

8 Individual case report – Case N34-WE

In this chapter, we describe the individual case reports. In the reports we describe the description of the case, the characteristics of the case and the case specific SE metrics and BVP metrics. We end every report with a brief summary and initial within-case conclusions. The information in the reports are the results of the interviews and document analysis. If Relatics is used to structure the SE process, we complement these results with data present in Relatics. The results provide insights in how SE is applied and how successful the project was in terms of BVP objectives budget, schedule and design process quality performance.

8.1 Characteristics of the case

Characteristic	Description
Projectname	Ombouw provinciale weg N34 gedeelte Witte Paal – Grens Drenthe
Client	Provincie Overijssel
Contract Tenderprocedure	Design & Construct based on UAC-ic EMVI
Client's expirience with SE	The client had experience with projects based on an integrated contract. Also, the client has experience with SE.
Activities	Reef Infra had to realize adjustments to the N34 over the length of 15.7km. Reef Infra has to deliver the following activities: • Realize five flyovers, crossovers, roundabouts, etc.; • Road structure of the N34; • Roads for yard access; • Realize parallel structure and cycling paths; • Realize noise reduction screens; • Realize fauna passage; • Realize rain storage systems.
Involved disciplines	Mainly road construction
Organization of the SE process	The SE process is organized within information management tool Relatics. The following aspects are organized in the Relatics information model: • Requirement Analysis • Functional Analysis • SBS • WBS • OBS • Interface management • Verification • VTW's

	• Risk analysis • Document management

8.2 SE metrics & Project success metrics

In this paragraph we present the SE metrics and BVP metrics as a result of the case study. First the SE performance project overview is presented to provide a complete picture of the SE performance in the case study. We continue by presenting the SE metrics and describing the evidence for the performance on individual SE-tasks. After this, we present the BVP objective metrics. We describe the evidence for the performance on individual BVP objectives. In both cases, the evidence consist of a summary of data sources and the within-case analysis.

8.2.1 Project overview

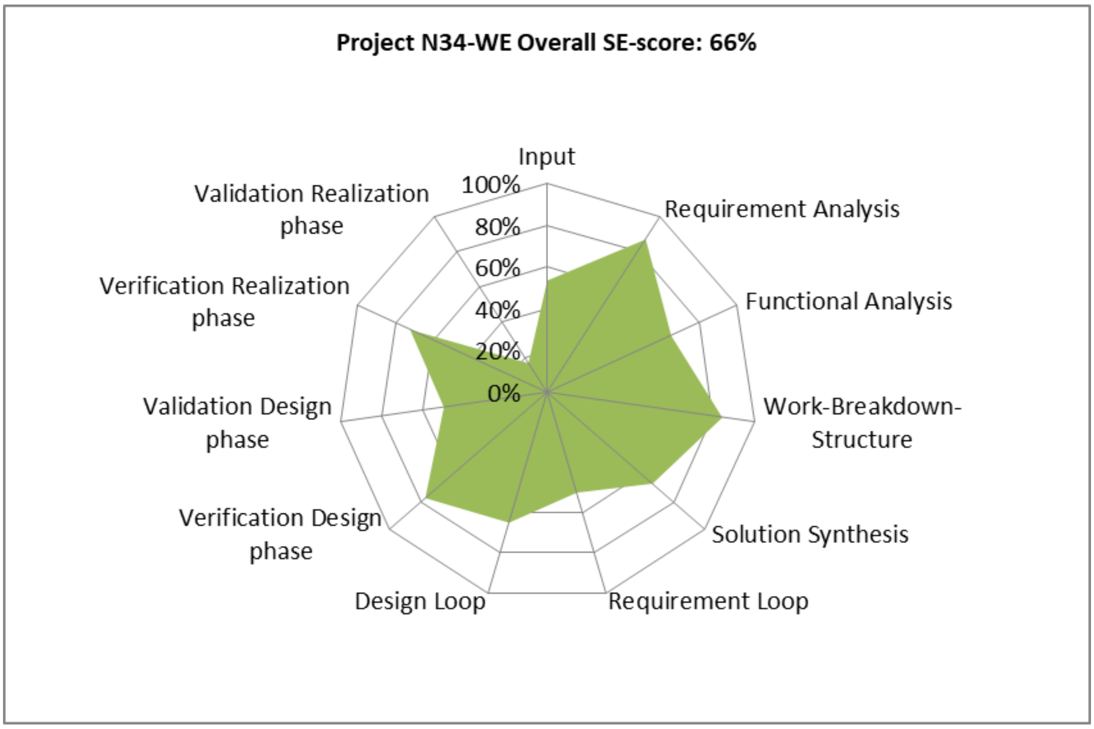

Figure 17: Overview SE-score N34.

8.2.2 SE metrics

First, we present an overview of the results of the SE performance measurement in the case study. After which we continue by presenting the evidence of the scores. The evidence consists of the data sources and the within-case analysis of every SE-tasks. The evidence is divided into three categories of performance:

10. what was done;
11. what was partially done;
12. what was not done.

Table 28: Overview scores individual SE tasks for case MDS-WA.

SE – task	Score [max 100%]
Input	54%
Requirement Analysis (RA)	87%

Functional Analysis (FA)	65%
Solution synthesis	67%
Output	75%
Requirement loop	50%
Design loop	65%
Verification Design phase	77%
Validation Design phase	50%
Verification Realization phase	72%
Validation Realization phase	17%
V-model	100%
Work-Breakdown-Structure (WBS)	85%
Overall SE	**66%**
Base process (RA, FA, WBS, Solution synthesis)	**76%**
Feedback process (Requirement loop, Design loop, Verific. Design, Valid. Design, Verific. Realization, Valid. Realization)	**55%**
Support process (V-model, Input, Output)	**76%**

Data sources

- Project documentation:
  - Contractdossier
    - Vraagspecificatie I
    - Vraagspecificatie II
    - Inschrijfleidraad
  - Project plans
    - Projectmanagementplan
    - Deelplan Kwaliteitsborging en Documentbeheer
    - Verificatie- en validatieplan
  - Verification en Validation:
    - Reports
    - Nota
  - Oplever- en/of restpuntenlijst
  - Termijnstaat
  - Schedule

- Interview #1 Peter Blom
  - Date: Datum
  - Location: Kantoor Reef Infra, te Oldenzaal
  - Duration: 1 hour and 15 minutes
  - Job description: Procesbeheersing (Ontwikkel- & Realisatiefase)
- Interview #2 Sander Kamphuis
  - Date: Datum
  - Location: Kantoor Reef Infra, te Oldenzaal
  - Duration: 1 hour
  - Job description: Procesbeheersing (Ontwikkel- & Realisatiefase)
- Interview #3 Rick Makkinga
  - Date: Datum
  - Location: Kantoor Reef Infra, te Oldenzaal
  - Duration: 1 hour
  - Job description: SE deskundige (Ontwikkel- & Realisatiefase
- Systems Engineering Poster session
  - Datum
  - Kantoor Reef Infra, te Oldenzaal
  - 2,5 uur

- Plenaire sessie

Within-case analysis

- Requirement Analysis (RA) (87%)
  - What was done:
    - The following sources were used for the Requirement analysis
      - Specification Requirements *(Vraagspecificatie I)* and Specification Process *(Vraagspecificatie II)*
      - Tender documents Reef Infra *(documentatie aanbieding)*
      - Compulsory and informative documents *(Richtlijnen, standaarden, etc.)*
      - Stakeholder analysis
    - The Specification Requirements were analyzed case-by-case.
    - The "Who-reads-What list" ensured that all available documentation is analyzed on additional requirements.
    - Requirements were integral analyzed by the project team.
    - The output of the requirement analysis is the "Requirements Tree".
    - The structure of the Requirements Tree provided by the client was taken over.
    - The Requirements were formulated SMART.
    - The description of the Recruitments were formulated.
    - The sources of the Requirements were described.
    - Requirement numbering is applied to increase traceability.
    - Verification and validation plan was based on the RA.
    - Requirements were allocated to the SBS.
    - Requirements types were allocated.
    - The requirements were allocated to related activities.
    - Underlying or Upper lying requirements were described for every requirement.
  - What was partially done:
    - None
  - What was not done:
    - The structure of the Requirements Tree provided by the Client was not checked for "fit-for-purpose".
    - The client requirement specifications were not made.
    - The level of detail for the requirements were not allocated.
    - The Requirements were not allocated to the WBS.

- Functional Analysis (65%)
  - What was done:
    - The output of the FA was the FBS
    - The FBS is structured as a Functions tree.
    - The correct formulation of the combination of a noun and a verb was used in the description of the function.
    - Functions were numbered to support demonstrability.
    - The output of the FA was the SBS.
    - The SBS is structured as an Objects tree.
    - Objects are numbered to support demonstrability.
    - The Object-requirement specification was made, therefore objects are linked to requirements.
    - The SBS was link to the RBS.

- What was partially done:
  - The V&V plan was adjusted based on the SBS and WBS but not based on the FBS and Object Specifications.
  - Adjustments to the V&V plan are recorded, however the reasoning behind the adjustments is not.

- What was not done;
  - The FBS was not linked to RBS, SBS and WBS.
  - The WBS was not linked to the SBS.
  - There are no Object specifications.

- Work-Breakdown-Structure (85%)
  - What was done:
    - The WBS was made in Relatics and linked to the RBS.
    - The WBS was revised based on the RA.
    - The output of the WBS is the Activities tree.
    - Activity - Requirements specifications were made.
    - Activity specifications were made in Excel/Word and combined in an overall Work plan (Werkpakketbeschrijving).
    - The risks allocated to activities are described in the WBS.
    - The WBS is revised based on the Functional Analysis.
    - Input for the Activity was allocated.
    - Output for the Activity was allocated.
    - The WBS is revised based on the Solution Synthesis.

  - What was partially done:
    - None

  - Wat was not done:
    - Activity specifications were not made in Relatics.

- Solution Synthesis (67%)
  - What was done:
    - Design solutions were based on object specifications.
    - Design solutions were based on the RBS.
    - Design solutions were developed after the Requirement Analysis.

  - What was partially done:
    - None

  - Wat was not done:
    - The project team already started designing during the RA and FA.

- Requirement loop (50%)
  - What was done:
    - The RBS is revised based on the functional analysis.

  - What was partially done:
    - Adjustments to the RBS were recorded but the reasoning behind the adjustments not.

  - Wat was not done:
    - None.

- Design loop (%)
    - What was done:
        - The RBS was adjusted based on Design Solution Synthesis.
        - The SBS was adjusted based on Design Solution Synthesis.
        - Object specifications were not adjusted based on Design Solution Synthesis.
        - The V&V plan was adjusted based on Design Solution Synthesis.

    - What was partially done:
        - Adjustments to the RBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the FBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the SBS were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the Object Specifications were recorded demonstrable, but the reasoning behind was not.
        - Adjustments to the V&V plan were recorded demonstrable, but the reasoning behind was not.

    - Wat was not done:
        - The FBS was not adjusted based on Design Solution Synthesis.

- Verification design phase (77%)
    - What was done:
        - Verification in the design phase is executing according to the V&V plan.
        - The following items were mentioned in the V&V plan Design Phase:
            - Requirement code;
            - Requirement description;
            - Upper lying Requirements;
            - Verification method;
            - Allocation to OBS;
            - Documents for evidence.
            - Result of the verification.
        - Verification was done on multiple abstraction levels.
        - Underlying Requirements and Objects and Upper lying Requirements and Objects were verified by making the connection.
        - Underlying Functions and Upper lying Functions were verified by making the connection.
        - The Verification report with evidence was made.
        - Adjustments to documentation was made when the verification results were not positive.

    - What was partially done:
        - None.

    - Wat was not done:
        - The following items were not mentioned in the V&V plan Design Phase:
            - Underlying Requirements;
            - Verification moment;
            - Activity number, to link the verification to the corresponding activities;
        - Adjustments to documentation caused by negative verification results were not recorded demonstrable.

- Validation design phase (50%)
  - What was done:
    - During the design phase validation was done to the first abstraction level (Validatie ontwerp overleg met Opdrachtgever).
    - During the design phase validation was done to the second abstraction level (Validatie ontwerp presentative met Omwonenden).
    - Based on the Validations, adjustments to documentation was made.
  - What was partially done:
    - None
  - Wat was not done:
    - There is no specific validation report.
    - Reasoning behind the adjustment to documentation was not recorded demonstrable.
- Verification realization phase (72%)
  - What was done:
    - Verification was done by inspection.
    - Verification was done to the first abstraction level.
    - Verification was done also to other abstraction levels.
    - The project team used the V&V plan to execute the Verification activities.
    - Verification report with evidence was made.
    - Document verification was executed.
  - What was partially done:
    - Adjustments to documentation was recorded demonstrable, however reasoning behind the adjustment was not.
  - Wat was not done:
    - The realized design solutions were not checked to see if these fulfill the functions.
- Validation realization phase (17%)
  - What was done:
    - None
  - What was partially done:
    - None
  - Wat was not done:
    - During the realization phase no validation was executed.
  -
- V-model (100%)
  - What was done:
    - Decomposition of the requirements, functions and objects was made in Relatics.
    - Specification and solution phase are connected by Objects – Requirements Specifications.
    - The disaggregation of design solutions was done.
  - What was partially done:
    - None

- Wat was not done:
  - None

8.2.3 Project success metrics

The project success metrics for the case study are presented in Table 8. The metrics comprise project success characteristics in terms of Budget performance, Schedule performance and Design process quality.

Table 29: Overview of the Project success metrics.

Project success indicators	Score
Budget Performance	Not delivered yet
Schedule Performance	Not delivered yet
Design process quality • # versions DO • # versions UO • # versions Ontwerpnota • # opleverpunten/restpunten • # afwijkingen • # VTW's	Not delivered yet

The BVP objective metrics are divided into Budget performance, Schedule performance and Design process quality.

The Budget performance is calculated as followed:

Budget Performance = Actual budget spent / Planned budget

The Schedule performance is calculated as followed:

Schedule Performance = Actual schedule / Planned schedule

These calculations provide factors to be able to compare project results. When the factor is close to zero, then the actual budget and schedule is the same as the planned budget and schedule.

Master's Thesis
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