Reducing failure costs in infrastructure construction by improving proceedings with requirements

A study of problematic human influence in processes with requirements at Boskalis Nederland

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Preface

This report presents the research I conducted for the completion of my master Construction Management and Engineering at the Delft University of Technology in The Netherlands. It describes a subject of interest of mine which was awakened by lectures about multiple new contract forms in the construction industry.

It came to my mind that these new forms of contracts not only shifted responsibility from the client to the contractor, but that the contractor completely had to embrace the delivery of new services and methods accompanied by these services. In other words, the same contractor had to provide services it was not used to provide by methods it was not used to apply. This major change in the entire market results in a challenging process reorganization combined with the application of new management techniques. It was this challenge I wanted to tackle during an eight-month research for my master thesis.

I would like to make use of this preface by thanking the members of the graduation committee for the knowledge, support and enthusiasm they transferred during the meetings. Especially the strong theoretical background, connected to a vast experience in practice has made the feedback from all of the members very valuable. The ongoing constructive criticism considering the optimization of the research and the completion of the report has had a major impact on the overall quality.

Special thanks goes to the 35 interviewees who found some time available for not only handing me the information I needed for the research, but also reviewing the information in order to make sure no flaws had contaminated the case descriptions. Furthermore, I would like to thank the employees at Boskalis Nederland, who were always available for a constructive discussion about my thesis and the results.

Finally, I would like to thank my family and friends for their perpetual support, motivational speeches and reviews but mostly for their trust and patience.

I hope you will enjoy reading the report and that you will not be reluctant to get in contact for any questions or discussion about the thesis.

Marcel Dammers
Rotterdam, 2016

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Management summary

This report describes the research which aims to find a solution to the problem that even though the contractor endeavors to verify all requirements in integrated infrastructural contracts following from the client's request, the contractor is still confronted with failure costs due to the lack of demonstrating the fulfillment of the clients' requirements. It will do so by providing recommendations on improved proceedings with requirements following from the client's request, in integrated infrastructural contracts, in order to reduce failure costs. This will be done by answering the following research question:

> Research question
> *Which proceedings with client's requirements, from requirement specification to completion, are responsible for failure costs and how can these proceedings be improved?*

In order to answer this research question, an exploratory case study of five embedded cases is executed at Boskalis Nederland. All of these cases are based on integrated contracts, are sufficient in financial and physical size to be a multidisciplinary project, had a duration of more than two years, and are at least in the execution phase. Furthermore, Boskalis Nederland had to have a financial influence in the project of minimal 50%.

The scope of the research starts with all the processes of an infrastructural construction project at Boskalis Nederland. The scope is narrowed down by assigning the problematic processes in the cases by two different approaches. This is done in order to increase the substantiation of these problematic processes. The first method used for specifying problematic processes per case analyses the course of the project based on a validated standard process from Boskalis Nederland. The second method checks whether potential causes for failure costs according to literature occurred in the cases. From there, the scope will focus on the problematic processes with requirements and the proceedings with requirements that occur in these processes. This is done by creating a model which describes the problematic processes and connects the human impact to it. The data which is input for the analysis of the projects is gathered through interviews with employees of Boskalis Nederland. The courses of the projects are estimated by interpretation of these interviews and are substantiated by internal project documents.

The analysis of the projects is executed by modelling the approach of an infrastructure construction process by Boskalis Nederland in an IDEFØ methodology. The model is validated by a check of the essential aspects of a process according to literature and contract management by Rijkswaterstaat, resulting in a validated standard process. The analysis of potential causes for failure costs according to literature is done by checking whether events that occurred in the cases match the described potential causes for failure costs. Based on the results of these analyses, the problematic processes can be summed up, and connected to the potential causes for failure costs. The problematic processes are as follows:

- Systems engineering
- Design
- Chance/risk management
- Interface management
- Organization management
- Cables and pipelines
- Verification process
- Execution
- Environmental findings

The problematic processes in which proceedings with requirements occur, can be visualized in the V-model. For contemplation of the human influence to the model, the certainty of performance and the level of detail are added. This adds the impact of interpretation and assumptions and therefore an important human influence. The focus of certainty is the result of a consideration of the triple constraint of project management. The normative performance is known and stipulated in a contract at the beginning of the project while costs and time are the result of the contractor's ability to meet the normative performance based on estimations, therefore the certainty of performance is connected to the V-model.

The goal of the preparation in the tender phase is to achieve a valid level of certainty of performance while assessing the remaining uncertainty as risk, in order to properly determine the projected cost and time. The goal of the preparation in the realization phase is to achieve a valid level of detail that enables the execution team to build what has been promised in the tender phase.

The level of detail can be approached by a weighted summation of the level of detail in the design and the level of known detail about the environment, as is described by the equation:

$$Detail_{project} = \alpha(Detail_{environment}) + (1-\alpha)\,(Detail_{new}),\text{ with}$$
$$\alpha = weighting\ factor\ impact\ of\ system_{environment}\ on\ system_{new} \in \{0;1\}$$

The deviation between actual and perceived certainty of performance is approximated by the description of the negative human influence in the cases. The origins of problems in the deviations can be process-oriented or human-oriented. Human-oriented problems can be the result of individual errors, or of errors resulting from an entire group.

For the analysis, the level of detail and certainty of performance are described at the start of the project, at the end of the tender, at the end of the preparation, and at the end of the execution. The elaborations per project and the comparison between the elaborations of all projects result in the designation of problematic proceedings with requirements.

Based on the analysis, the proceedings with requirements that are responsible for failure costs are (1) assumptions on the soil quality without the assurance through risk assessment, (2) individual errors which are not corrected by iteration, (3) design decisions in the preparation phase which are not in line with the contract, and (4) the lack of a level of detail in the design at the end of the preparation phase.

The origins for these problems are assignable to (A) the lack of a process which describes the assessment of the original situation, (B) a mentality which is not intrinsically risk driven, (C) the lack of a focus on the contract and the associated requirements as the base of the project combined with a lack of an integrated approach, and (D) the lack of attunement about the minimal level of detail needed for construction. These origins mainly emerge in the contractors new responsibilities which follow from the application of integrated contracts.

The recommendations for improving these problematic proceedings following from the research can be top-down process interventions, or bottom-up mentality adaptions. The recommended process interventions are to (I) incorporate the assessment of the environment and the soil quality into the project management system, (II) demand insight in the risk exposure of a project by the company management, (III) periodically organize combined risk-interface sessions in which employees discuss the course of the project and potential problems, (IV) verify requirements after adaptions in the contract, design or processes, and (V) ensure formal agreements about a minimal level of detail between the executor and the designer at the beginning and end of the design phase.

In the long run, mentality adaptions which can be reached through organizational change focusing on risk- and contract-based decision making will contribute to the prevention of failure costs resulting from proceedings with requirements

Management samenvatting

Dit rapport beschrijft het onderzoek met als doel het vinden van een oplossing voor het probleem dat ondanks het feit dat de opdrachtnemer alle klanteisen in geïntegreerde contractvormen poogt te verifiëren, er faalkosten ontstaan door het niet aantoonbaar voldoen aan de eisen. Dit wordt gedaan door aanbevelingen te doen over een verbeterde omgang met klanteisen in geïntegreerde contractvormen om zo faalkosten te kunnen verminderen. De onderzoeksvraag die hiervoor centraal staat is als volgt:

Onderzoeksvraag
Welke handelingen met eisen, van vraagspecificatie tot oplevering, zijn verantwoordelijk voor faalkosten en hoe kunnen deze handelingen worden verbeterd?

Handelingen met eisen worden hierin beschouwd als de menselijke invloed op het proces met eisen. Om de vraag te kunnen beantwoorden wordt een ingebedde verkennende casestudie uitgevoerd waarin vijf projecten worden geanalyseerd bij Boskalis Nederland. Alle projecten zijn gebaseerd op geïntegreerde contracten, zijn voldoende van fysieke en financiële omvang om een multidisciplinair project te zijn en hebben minstens twee jaar geduurd. Bovendien is Boskalis Nederland voor minstens 50% financieel verantwoordelijk voor alle projecten en zijn de projecten in de uitvoeringsfase en gaan ze richting oplevering.

De scope van het onderzoek begint met alle processen die nodig zijn in een infrastructureel project volgens Boskalis Nederland. De scope wordt verkleind door het aanwijzen van de problematische processen middels twee verschillende methodes. De eerste methode focust op een analyse van het verloop van de processen op basis van een standaard proces van Boskalis Nederland welke wordt gevalideerd. De tweede methode is een analyse van het optreden van potentiele oorzaken voor faalkosten volgens de literatuur. Vanaf daar zal de scope zich focussen op de problematische processen waarin handelingen met eisen plaats vinden. Dit wordt gedaan door een model te maken waarin de problematische processen worden beschreven waar de menselijke impact aan wordt gekoppeld. De data die nodig is voor deze analyses wordt verkregen door het schetsen van het verloop van de projecten op basis van interviews waarna dit verloop wordt onderbouwd door interne projectdocumenten.

De analyse naar het verloop van de projecten wordt uitgevoerd door het standaardproces volgens Boskalis Nederland te modelleren middels een IDEFØ methodologie. Het model wordt daarna gevalideerd door te controleren of alle essentiële aspecten voor een proces in het model zitten op basis van literatuur en contractbeheersingstechnieken van Rijkswaterstaat. De analyse naar potentiele oorzaken voor faalkosten volgens literatuur wordt gedaan door te controleren of de oorzaken op zijn getreden tijdens het proces. De resultaten van deze analyse kunnen met elkaar worden vergeleken om de problematische processen als volgt op te sommen:

- Systems engineering
- Ontwerp
- Kans- en risicomanagement
- Raakvlakmanagement
- Organisatiemanagement
- Kabels en leidingen
- Verificatieproces
- Uitvoering
- Omgevingsvondsten

De problematische processen waarin eisen worden behandeld kunnen worden gevisualiseerd in het V-model. Om de menselijke impact aan het model te kunnen koppelen, wordt de zekerheid van prestatie en het detailleringsniveau toegevoegd. Op deze manier kan de invloed van interpretatie en aannames worden beschouwd in het model. De focus van zekerheid op de prestatie is het gevolg van het uitgangspunt waarin tijd, prestatie en kosten worden beschouwd als leidende factoren voor een project. De prestatie is normatief en staat vastgelegd in het contract aan het begin van het project waardoor vanaf het begin zeker is wat er verwacht wordt, waar tijd en geld het resultaat zijn van het vermogen van de opdrachtnemer om een goede projectie te maken.

Het doel van de voorbereidingen in de tender is om een zo hoog mogelijke zekerheid van prestatie te bereiken op basis waarvan de kosten en de tijd kunnen worden bepaald. Het doel van de voorbereiding in de realisatie is om een detailleringsniveau te halen waarmee het uitvoeringsteam begrijpt wat er gemaakt moet worden om te voldoen aan de tenderbeloftes.

Het detailleringsniveau kan worden bepaald door een gewogen gemiddelde te berekenen van het detailleringsniveau van het ontwerp en het bekende detail van de omgeving waarin gebouwd gaat worden, als beschreven in de volgende vergelijking:

$$Detail_{project} = \alpha\left(Detail_{omgeving}\right) + (1-\alpha)\,(Detail_{nieuw}), \text{ met}$$
$$\alpha = weegfactor\ van\ de\ impact\ van\ systeem_{omgeving}\ op\ systeem_{nieuw} \in \{0;1\}$$

Het verschil tussen de eigenlijke en waargenomen zekerheid van prestatie wordt benaderd door de beschrijving van de negatieve menselijke impact in de projecten. De oorzaken voor deze afwijkingen kunnen proces georiënteerd zijn of op basis van menselijke invloed, welke weer op te delen is in individuele invloed of groepsinvloed.

Voor de analyse wordt het detailleringsniveau en de zekerheid van prestatie bepaald aan het begin van het project, aan het einde van de tenderfase, aan het einde van de voorbereidingsfase en aan het einde van het project. De beschrijvingen worden per project beschouwd en vergeleken om de problematische handelingen met eisen te kunnen bepalen.

Op basis van de analyse kunnen de handelingen met eisen die verantwoordelijk zijn voor faalkosten worden opgesomd als (1) aannames betreffende de bodemkwaliteit zonder daar risico's aan te koppelen, (2) individuele fouten die niet worden verbeterd na iteratie, (3) ontwerpbeslissingen welke niet in lijn zijn met het contract en (4) het gemis aan detailleringsniveau aan het eind van de voorbereidingsfase.

De oorzaken van deze problemen zijn (A) het gemis van een proces waarin de beoordeling van de originele situatie wordt beschreven, (B) een mentaliteit die niet intrinsiek risicogericht is, (C) het gemis aan focus op het contract en bijbehorende eisen als basis van het project gecombineerd met een gemis aan integrale aanpak en (D) het gemis van afstemming over het minimaal benodigde detailleringsniveau voor uitvoering van het werk. Deze oorzaken zijn grotendeels te vinden in de opdrachtnemers nieuwe verantwoordelijkheden als gevolg van integrale contracten als risicomanagement en contract gestuurd werken.

De aanbevelingen voor het verbeteren van deze problematische handelingen, op basis van dit onderzoek, kunnen top-down procesinterventies of bottom-up mentaliteitsaanpassingen zijn. De procesinterventies behelzen het (I) opnemen van de beoordeling van de originele situatie in het project management systeem, (II) het eisen van inzicht in het gevolg van risico's op het project vanuit de directie, (III) het periodiek houden van gecombineerde raakvlak- en risicosessies waarin het verloop van het project en potentiele risico's worden besproken, (IV) het opnieuw verifiëren van eisen na aanpassingen in het contract, ontwerp of proces en (V) een formele overeenkomst over het minimaal benodigde detailleringsniveau voor uitvoering tussen de uitvoerder en ontwerper aan het begin van de ontwerpfase.

Op de lange termijn zouden mentaliteitsaanpassingen middels verandermanagement met de focus op risico- en contract-gestuurde besluitvorming bijdragen aan het voorkomen van faalkosten als gevolg van problematische handelingen met eisen.

1. Introduction

Failure costs in Dutch infrastructure construction are estimated at €1 billion a year. This enormous amount is a result of failure cost estimates differing between 7% and 11% of the total costs of an infrastructural project (Bouwkennis, 2013) (USP Marketing Consultancy bv, 2008) (USP Marketing Consultancy bv, 2010) and a Dutch annual budget for infrastructure construction in 2016 estimated at €12 billion (Koning & Van Elp, 2011).

Failure costs are considered as costs of quality due to internal and external failures which are higher than the costs needed to prevent them. The definition will be elaborated in paragraph 4.2. According to this definition, €1 billion a year on costs due to failure could be prevented. When this is regarded in combination with an increase in project size and complexity, changing contract types and a resulting shift in responsibility, the need for control of failure costs is evident.

A changing market

In former contract forms the client was responsible for delivering a design in the tender phase ready for execution. Several contractors provided a price for which the project could be built and the client chose the cheapest variant, making the price dominant. The knowledge and experience with execution lies with the contractor, but the risks for the project were the responsibility of the client. This had the potential to lead to a paradigm in which flaws in the design are not mentioned by the contractor, but are seen as a financial benefit since they would lead to more work. A contractor could be looking for errors in the design and use the financial benefit to lower the tender price. That way, errors in the design by the client could lead to higher costs for the client where and a benefit for the contractor.

Another downside of these old contract forms is that when a project was finished, the client could not prove that the contractor delivered what the client requested. There was no assurance of the quality of the construction and the extent to which it matched the designs.

In the new contract forms, the client wanted to shift the responsibility and risk to the contractor via the application of integrated contracts. In this integrated approach, the client comes up with a list of functional requirements the project has to live up to and then leaves the responsibility for design, risk management, execution and verification of the project to the contractor. Contractors now have a complete new field of business by incorporating design and risk management in the process. One of the tools, requested by numerous clients, which is believed to ensure a proper process in this new field of business is systems engineering.

Systems engineering and requirements

The primary goal of systems engineering is reducing the risk associated with new systems or modifications to complex systems (INCOSE, 2006, p. 2.5). Systems engineering therefore aids in the transition towards new contract types. It sets the focus on the contract and the requirements, but the transition towards this completely new way of business and contracts has its problems, also at contractor Boskalis Nederland.

In a preliminary research in which interviews with several employees of Boskalis Nederland have been held, problems emerging in the process have been discussed in which the focus was on requirements. These requirements form the basis of the design and the project and therefore of the contract. The client has to specify these requirements on the level of functions rather than products. The contractor then has to interpret these requirements and translate them into a product based solution for the specific combination of functions. According to the interviewees, it is this interpretation in translation of requirements which has caused multiple long-lasting discussions between contractor and client and therefore leads to failure costs. Based on these interviews, it can be stated that the client is not always satisfied with the way the solution for the requirement specification has come together. This is the starting point for this report.

2. Methodology

This chapter describes the methodology of this research and therefore the process for obtaining a substantiated conclusion.

At first the structure of the research will be described, then the problem formulation, research objective and research question are stated in order to define respectively the starting point of the research, the goal of the research and the means for reaching that goal. After that, the scope of the research will be visualized and the question and objective are divided into sub questions and sub objectives.

When the structure of the research is clear, the strategy for the research is described by means of a research framework, methods for data selection and ways of establishing the quality of the research. Finally, a hypothesis will be stated.

2.1 Problem formulation, research question and research objective

As mentioned in the introduction, there is assumed to be a problem with the translation of requirements into satisfying decisions for the client according to the interviews. This report endeavors to find a solution for a better alignment of the decisions to the requirements. This will start with defining a problem definition, which will act as the starting point of this report. After that, a research objective will be stated in order to determine the intended end point of the research. A research question will then try to connect the problem to the objective.

The introduction has shown that the assumed problem is a result of the preliminary research. Based on the interviews in this preliminary research the following problem definition will be assumed valid for the setup of the main research. The problem definition has to be verified later on in the process. The problem formulation is stated as follows:

> <u>Formulation of the problem:</u>
> *Even though the contractor endeavors to verify all requirements in integrated infrastructural contracts following from the client's request, the contractor is still confronted with failure costs due to not demonstrable fulfillment of the client's requirements.*

In order to fully comprehend the problem formulation, the question will be divided into smaller elements.

Problem element 1 – *Even though the contractor endeavors to verify* – is an assumption of the current situation. It focuses on the benevolence of the contractor to verify and draws light on how the verification process is organized.

Problem element 2 – *all requirements in integrated infrastructural contracts following from the client's request* – sets the scope of the problem. The focus will merely be on the client's requirements specified in the contract and on infrastructural projects with integrated contracts.

Problem element 3 – *the contractor is still confronted with failure costs* – defines the real problem; the occurrence of failure costs. The definition of failure costs will be specified in paragraph 4.2.1.

Problem element 4 – *due to not demonstrable fulfillment of the clients' requirements* – defines the scope even further by setting the conditions of the failure costs in order to be taken into consideration for this research. It describes that the contractor might or might not have built according to the requirements, but that there is no clear demonstration of it.

Since the problem is clear now, the goal of the research can be defined in the form of the research objective. This can be stated as follows:

> Research objective:
> *Provide recommendations on improved proceedings with requirements following from the client's request, in integrated infrastructural contracts, in order to reduce failure costs.*

Again, a division into elements will help to better understand the objective.

Objective element 1 – *Provide recommendations on improved proceedings with requirements* – defines the goal of the report and also implies that improved proceedings with requirements will contribute to solving the problem. It is important to realize that the word proceeding is used in order to be able to consider all aspects of coping with requirements, from interpretation or design, to processing them. Proceedings are defined as the human influence in the process. The design process for instance consists of proceedings such as requirement interpretation, translation of requirements to design decisions and verification of requirements in the design.

Objective element 2 – *following from the client's request in integrated infrastructural contracts* – again defines the scope of the research, as has been seen in the problem formulation.

Objective element 3 – *in order to reduce failure costs* – states the result the recommendations eventually have to lead to and therefore the reason for this report.

Having stated the start of the research in the problem definition and the end of the research in the research objective, a connection can be made by defining the method of research. As can be abstracted from the previous, the research question will have to aid in providing recommendations to reduce failure costs. The research question is stated as follows:

> Research question
> *Which proceedings with client's requirements, from requirement specification to completion, are responsible for failure costs and how can these proceedings be improved?*

Now the research question will be divided into several elements again.

Question element 1 – *Which proceedings with client's requirements* – sets the focus on a specific part of the problem definition; only the proceedings with client's requirements and not the requirements itself.

Question element 2 – *from requirement specification to completion* – defines the parts of the process in proceedings with requirements that will be assessed. In this case, the entire process of which the responsibility lies with the contractor. This starts with receiving the tender documents from the client and ends with the delivery of the project and the associated documents to the client.

Question element 3 – *are responsible for failure costs* – states the limits of this research. Only the most important proceedings will be considered, since this will create the most benefit. The importance and the impact of the proceedings will be regarded based on consideration of the influence the proceedings have on budget, time and quality.

Question element 4 – *and how can these proceedings be improved* – creates the link between the research question and the research objective.

2.2 Focus and scope of the research

The research will be conducted at Boskalis Nederland, so the research will be carried out from a contractor's perspective. The choice for this research perspective is made because the current integrated contracts shift the responsibility and risk from the client to the contractor. A research from a contractor's perspective provides insight in the problems that emerge in coping with this responsibility. The goal of the research is to provide a general recommendation for better proceedings with requirements for contractors.

The scope of the research is framed by considering integral approaches and will focus on multidisciplinary, infrastructural projects with integrated contracts. In order to ensure substantiated embedded case studies, the analyzed projects have to meet specific requirements for selection, which are elaborated in chapter 5. Since requirements form the basis of the contract and therefore the projects, the thread of the research will be proceedings with requirements.

It is evident that the research concerns the causal relationships between several proceedings on the one hand, which result in the failure costs on the other. The research perspective will take the form of a causal conceptual model which will be used in evaluating proceedings with requirements.

The scope of the research will initially focus on all the processes in infrastructure construction at Boskalis Nederland, from requirement specification to completion. From there, the most problematic processes are distinguished as is described in paragraph 2.4. After that, the scope will be delimited to problematic processes at with requirements at Boskalis Nederland, as can be seen in Figure 1.

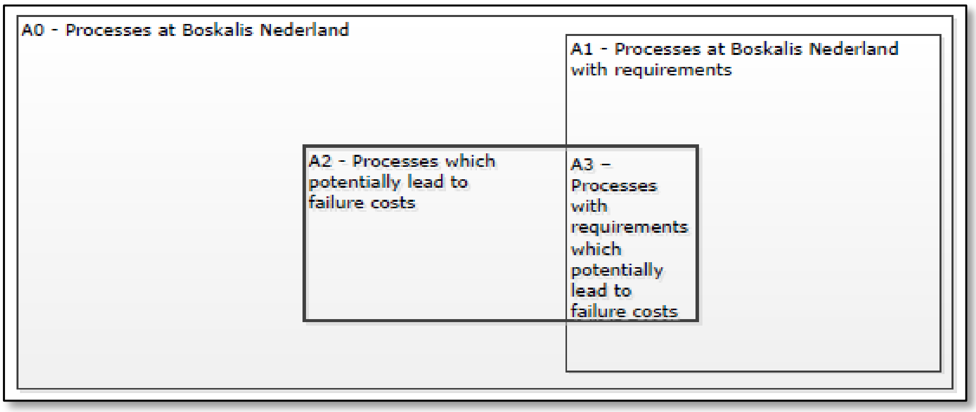


Figure 1 – The scope of the research (own ill.)

The initial scope of the research is described by the large rectangle A0, as can be seen above. As the research proceeds, the problematic processes which potentially lead to failure costs will emerge and the scope of the research will reduce to the smaller rectangle A2. From there, the research will focus on the problematic processes with requirements as can be seen in the smallest rectangle A3. The scope focusses completely on Boskalis Nederland.

2.3 Sub objectives and sub questions

Now we know the structure of the research, we can start to further describe the process and methods. First, the research objective will be operationalized by formulating sub objectives, and then sub research questions will be connected to them. The problem definition will not be divided into sub problem formulations since the starting point is the same for all sub objectives. The sub objectives can be divided as follows:

1. Identify (a) the proposed proceedings at Boskalis Nederland which handle requirements and (b) potential causes for failure costs, by conducting a literature study, analyzing internal processes and conducting interviews
2. Identify the problematic processes and potential causes for failure costs by analyzing several infrastructure projects
3. Provide theory from literature on the problematic processes and causes for failure costs in order to ensure a substantiation for the recommendations
4. Identify the problematic proceedings with requirements and recommending improvements on these proceedings.

The sub questions are formulated as follows:

1. What are the problematic processes at Boskalis Nederland per case based on (a) a comparison between the course of the projects and a validated standard process and (b) a comparison of this course to potential causes for failure costs from literature?
2. What is the impact of human handlings in the problematic processes at Boskalis Nederland which handle requirements and how can this be visualized in a model?
3. What is the human influence per case and how do the influences per case compare?
4. Which causes for failure costs are assignable to the cases based on the analysis and what are the origins of these causes?
5. How can the analyzed failure costs be prevented?

2.4 Research framework and formulation

The research process is divided in the stages orientation, data gathering, data analysis, data interpretation and evaluation. Implementation of the recommendations is included in the visualization on Figure 2, but will not be described in this report.

An important distinction in this report is made between process and proceedings. A process is regarded as a combination of proceedings. Proceedings are defined as the human influence in the process. This distinction is made since the first part of the research focusses on determining the problematic processes after which the problematic proceedings in these processes are determined.

A key element of the research is the analysis of five infrastructure projects at Boskalis Nederland. These analyses will be based on (1) deviations in the analyzed projects from a standard process at Boskalis Nederland which is validated and (2) on the occurrence of events which are potential causes for failure costs according to literature. These approaches will help in defining which events occurred different than planned and therefore sharpen the scope of the research. Combining the approaches will result in an overview of the most important problems in processes, after which the proceedings with requirements in these most important problems can be considered.

The research will conclude with recommendations on the proceedings with requirements in these most problematic processes. This is visualized in Figure 2.

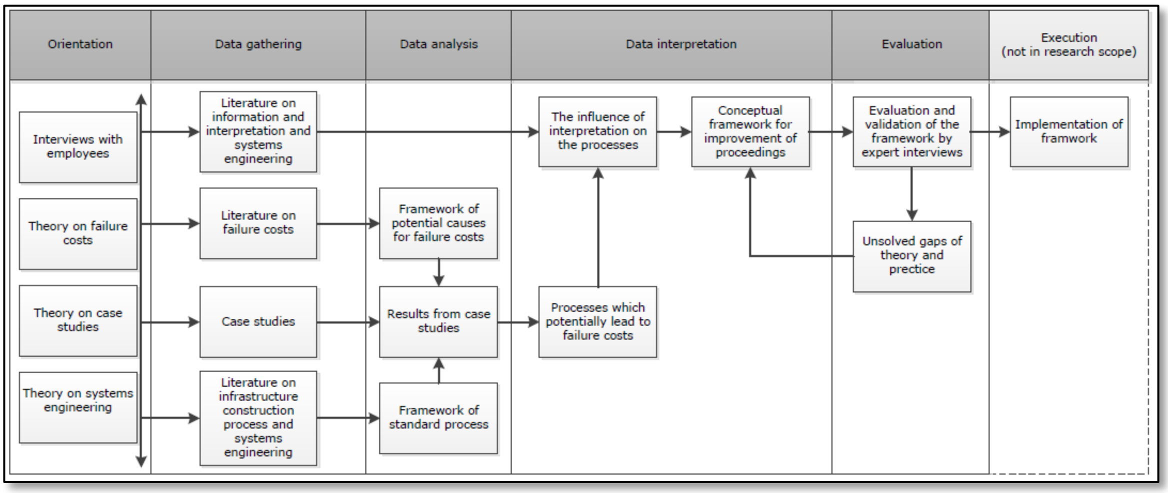


Figure 2 – Schematic representation of the research process (own ill.)

The figure above shows the different phases of the research at the top, covering the orientation phase, the data gathering phase, the data analysis phase, the data interpretation phase, the evaluation phase and eventually the execution phase. This last phase is shown as light grey since it is not elaborated in this report. The orientation phase consists of consulting literature on several topics and orientating interviews. The data gathering phase focusses on retrieving information from the different cases and connecting them to the frameworks from literature. The data analysis will show the results from the connection after which processes which potentially lead to failure costs are identified. The data interpretation phase will then designate the problematic proceedings with requirements in the cases after which the results are evaluated.

The research framework as can be seen above is formulated as follows:

<u>Formulation of the research framework:</u>
This research is a study from a contractor's perspective on the proceedings with a client's requirements, from requirement specification to completion, which result in failure costs, based on scientific literature and multiple, embedded case studies.

A confrontation of the results of the case studies with the proposed processes at Boskalis Nederland and processes based on literature should result an overview of problematic processes. Combining the human influence to these processes in a model leads to the designation of dominant proceedings for failure costs will eventually lead to recommendations for improvement of these problematic proceedings.

2.5 Research strategy and material

The research will be a diagnostic, deepening, explorative, empirical research in which multiple embedded case studies will be executed.

The strategy to answer sub questions starts with defining in which phase of the research the question will be answered. The research process is divided in the stages orientation, data gathering, data analysis, data interpretation and evaluation. This is schematically presented as can be seen in Figure 3.

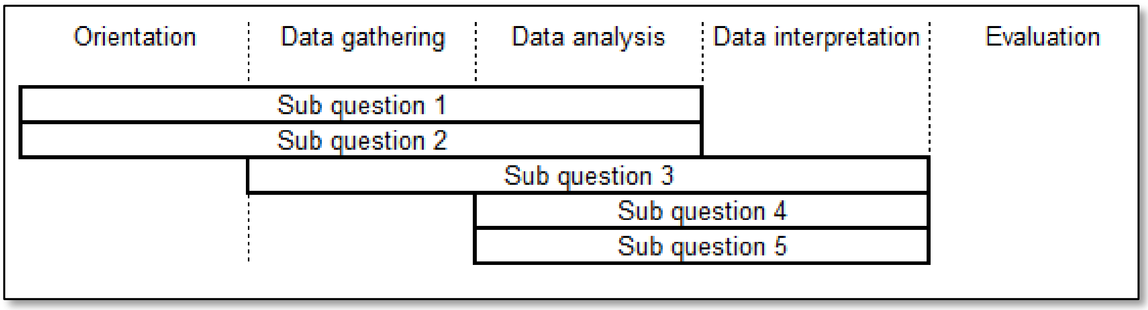


Figure 3 – sub questions per research phase (own ill.)

The figure above shows again the different phases of the research at the top, covering the orientation phase, the data gathering phase, the data analysis phase, the data interpretation phase, and the evaluation phase. Per phase the regarded sub questions are shown. Sub question 1 and 2 are considered in the first three phases, sub question 3 is considered in the data gathering, and data analysis phase. And sub question 4 and 5 are considered in the data analysis and interpretation phases.

2.5.1 The next table provides an overview of the selection of materials per sub question.

Question	Research object	Information type	Method
1.	Process, documents, employees	Scientific literature, reality, documents, individual people	Articles, content analysis, questioning
2.	Process, documents	Scientific literature, documents	Articles, content analysis
3.	Process, documents, employees	Scientific literature, reality, documents, individual people	Content analysis, questioning
4.	Process, employees	Documents, individual people	Content analysis, questioning
5.	Process, documents employees	Scientific literature, reality, documents, individual people	Content analysis, questioning

Table 1 – Selection of materials

The table above shows the five different sub questions and the way they will be answered. The research object per question determines the character of the subject to research. The information type shows the kind of information that will be investigated and the method describes the form that information is in.

2.5.2 Research objects

The research objects will differ along the research. At first, processes will be analyzed in order to create a clear view of processes which potentially host proceedings which result in failure costs. After that, the proceedings with requirements within these processes will be considered. The reported shortcomings, negative findings or other types of comments which pinpoint a not demonstrable fulfillment of the clients' requirements will also be investigated.

2.6 Data selection protocol

According to Verschuren and Doorewaard, information can be extracted from a literature study, surveys, in-depth interviews and other documentation (Verschuren & Doorewaard, 2010). This paragraph will regard the role of the used sources in the research.

The core of this research is the distinction of dominant proceedings for failure costs based on analyses of five cases. In order to be able to comprehend the events per case, several interviews with employees will be held. The designated problematic events resulting from these interviews will be substantiated with internal documents in order to ensure an objective course of the project. Two different approaches for the analysis of the embedded cases will be applied based on literature studies. The methods used for this research therefore are a literature study, in-depth interviews and the analysis of documentation.

2.6.1 *Literature study*

The literature study will focus on the theory and definitions of systems engineering, failure costs, and certainty, uncertainty and risk in order to provide a theoretical background as starting point of research. Furthermore it will provide theory on the methodology of embedded case studies, since they have such a prominent role in the research. The literature study will contribute to answering questions 1 and 2.

2.6.2 *In-depth interviews*

The results of these in-depth interviews will aid in describing the course of the cases which can then be substantiated by other documentation. The in-depth interviews will contribute to answering question 3 and 4. These interviews are of great importance to the outcome of the research and provide the main data for the report.

2.6.3 *Other documentation*

Other documentation entails project documents from the cases and internal documents from Boskalis Nederland. These documents can be minutes, current state reports or tables and figures which contribute to the research. These documents will aid in the embedded case studies and therefore answer question 3 and 4.

Since the embedded case studies are of major importance for this research a case study protocol is written in order to ensure the quality of these embedded case studies. This protocol can be found in Appendix I – Case study protocol.

2.7 Establishing the quality of the research

According to Yin, the quality of research can be established by testing construct validity, internal validity, external validity, and reliability (Yin, 2003, p. 34). Each test will be elaborated here shortly.

2.7.1 *Construct validity*

The aim of the test for construct validity is to make sure measures for the concepts being studied are operationalized (Yin, 2003, p. 35). For this research it means that the concepts as failure costs, systems engineering, risk, and level of detail are unraveled and downsized by attaching a stipulate definition to each of the key concepts by listing the dimensions and aspects (Verschuren & Doorewaard, 2010, p. 147).

2.7.2 *Internal validity*

The aim of the test for internal validity is to establish a causal relationship, in which certain conditions are shown to lead to other conditions, as distinguished from false relationships. For this research it means that the following questions will be regarded when drawing conclusions:

- Is the inference correct?
- Have all the rival explanations and possibilities been considered?
- Is the evidence convergent?
- Does it appear to be airtight? (Yin, 2003, p. 36)

2.7.3 *External validity*

The goal of external validity is to establish the domain to which a study's findings can be generalized. Replication of findings contributes to a strong external validity (Yin, 2003, p. 27). For this research conducting multiple embedded case studies will contribute to external validity by delimiting the type of projects.

The selection of cases for this research, do not all cover the same domain of infrastructure construction. This makes replication of findings difficult. Reaching external validity therefore is a compromise trying to cover all possible problems and substantiating the outcomes both as well as possible. The validity of the model following from the analysis will be ensured by regarding the extent to which the model can be generalized for these specific types of projects. The external validity will furthermore be reached by reflecting on the methods used, the contribution to literature and the case studies.

2.7.4 Reliability

Reliability can be stated as the demonstration that the operations of a study – such as the data collection procedures – can be repeated, with the same results (Yin, 2003, p. 36). A case study protocol could have major influence on the reliability of the research. Furthermore, the findings and conclusions from the case studies will be documented in such a way, that every assumption can be traced back to the origin.

2.8 Hypothesis

This paragraph will state a hypothesis which is used as a guidance throughout the research. The hypothesis will first aid in defining the problematic processes and in defining the human impact on the processes. The methods for doing so are elaborated after the hypothesis is stated. The hypothesis is based on multiple sources. An elaborate description of potential causes for failure costs based on literature is elaborated in paragraph 4.2. This paragraph will focus on the causes for failure costs which are stated to have the most impact by several sources.

According to the International Council on Systems Engineering (INCOSE) "many projects are driven by eager project champions who want "to get on with it." They succumb to the temptation to cut short the concept stage, and they use exaggerated projections to support starting detailed design without adequate understanding of the challenges involved. Many commissions reviewing failed systems have identified insufficient or superficial study in the concept stage as a root cause of failure" (INCOSE, 2006, p. 3.7). So the hypothesis according to INCOSE has to focus on the concept stage of the project with the emphasis on the level of detail of the study.

USP marketing consultancy states that the most influential aspects on failure costs are poor communication between decision makers and a design which is impracticable and therefore not ready for construction (USP Marketing Consultancy bv, 2010). Furthermore, an effective risk management process is also critical. It enables project managers to monitor risks and identify when they need to put a mitigation plan in place to actively manage them (PWC, 2013). USP marketing consultancy therefore focusses the hypothesis on the role of communication and risk management in the creation of the design.

Another investigation which has been executed by Bouwkennis also designates an impracticable design and communication flaws as the most important causes for failure costs (Bouwkennis, 2008).

The hypothesis for this research will be a combination of the previous statements and will focus on the level of detail and the practicability of the design and the extent in which risk management is effectively applied. A practicable design with effective risk management as a result of a deepening study in the concept stage should, according to the previous literature, lead to prevention of failure costs. Since the degree of depth of a study is qualitative and not directly correlated to the quality and practicability of a design, the focus will be on the practicability, rather than the deepening study. Therefore, the hypothesis which is used for this research is stated as follows:

Hypothesis
The extent to which a design is practicable combined with the extent to which risk is assessed, are proceedings which lead to failure costs.

In the first part of this research, the problematic processes will be designated based on potential causes for failure costs and a validated standard process. When risk management and creation of the design are among the problematic processes, the hypothesis will not be rejected.

If the hypothesis is not rejected, it will aid in setting the focus for the second part of the research. When the human influence is attached to the model that describes the problematic processes in which requirements are handled, the design should be among the problematic processes in the model and risk has to be incorporated as well. If the hypotheses is rejected, a new hypothesis will be stated for the creation of the model.

3. Literature overview

This chapter describes the literature used for this research and the motivation behind the choice for the specific authors. The reason for using literature in this research has been stated in paragraph 2.6.1. At first the literature for the different approaches of the cases will be considered. This can be divided into literature about processes in infrastructure construction and literature about failure costs in infrastructure construction. After that, literature about proceedings with requirements will be described and the influence of certainty, uncertainty and risk will be considered.

3.1 Different approaches of problems

This paragraph describes which literature will be used for the first analysis of the cases.

3.1.1 An approach based on a standard process

Internal documents of Boskalis Nederland will help providing a substantiated general process for the objective description of the cases. The internal project management system describes the processes as intended by employees responsible for safety, health, environment, and quality management. The processes retrieved from these internal sources will be described using the IDEFØ method. IDEFØ is a method for modeling decisions, actions, and activities of an organization.

The reason that IDEFØ is used as a modeling style is that the influence of the human factor and the role of organization can be integrated in the visualization. Process model techniques as Business Process Model and Notation (BPMN), Cognition enhanced Natural language Information Analysis Method (CogNIAM) or Event-driven process chain (EPC) describe a course of processes merely based on the outcomes of previous processes. The IDEFØ methodology describes processes not only based these outcomes, but also on human influence and tools for the processes. Since the hypothesis for this research focusses on the human influence on and the proceedings with requirements, IDEFØ is considered to be the best modeling tool for this research.

In order to validate the process proposed by Boskalis Nederland and make it applicable for research, systems engineering will be considered, as is described in paragraph 3.2.1. This will be done since the scope of the research focusses on proceedings with requirements that occur in processes with requirements. Processes concerning requirements are subject to systems engineering and therefore, a systems engineering approach will be suitable for validation of the process for this research. Next to the systems engineering approach, also a project management approach by De Ridder (De Ridder, 2013) and the system oriented contract management approach by Rijkswaterstaat (Rijkswaterstaat, 2011) will be analyzed. This way, the validation will be based on the conditions of multiple actors.

3.1.2 An approach based on failure costs from literature

The cases will also be analyzed based on theoretical origins for failure costs. In order to create an overview of these origins for failure costs, several sources will be consulted for a substantiated summation. The majority of the documents will be written on Dutch infrastructure construction, but in order to increase the scope of the research, also some international documents will be taken into account.

For the categorization of potential causes for failure costs, documents from the economic institute for construction (Koning & Van Elp, 2011), the independent market analyst USP marketing consultancy (USP Marketing Consultancy bv, 2008) (USP Marketing Consultancy bv, 2010), and of knowledge center Bouwkennis (Bouwkennis, 2008) (Bouwkennis, 2013) will be considered. These institutions describe the causes for failure costs in Dutch infrastructure construction based on different independent market analyses.

International research on causes for failure costs which are taken into account are the an independent research by PWC describing failure costs of capital projects in general (PWC,

2013) and a research by Flyvbjerg, Mette, & Soren describing failure costs specifically in infrastructure (Flyvbjerg, Mette, & Soren, 2004). These authors were chosen due to the independent nature of the researches and the difference in focus.

3.2 Proceedings with requirement and the human influence

Once the processes which do not occur as planned or the processes that potentially result in failure costs are identified, the proceedings within these processes will be considered. In order to do so, systems engineering and certainty, uncertainty and risk will be described taking the following literature in account.

3.2.1 Systems engineering

In order to create a general understanding of systems engineering, literature from the international council on systems engineering will be considered (INCOSE, 2006). INCOSE is a nonprofit organization founded in 1990 with the target to promote the application and development of systems engineering (INCOSE, 2016). Since systems engineering is an integrated and structured approach developed in defense industry in the United States of America (INCOSE, 2016), literature by the US Department of Defense will be taken into account as well (US Department of Defense, 2001).

Two step by step approaches of systems engineering are described by Wasson and Sage & Armstrong (Wasson, 2006), (Sage & Armstrong, 2000). These books have been chosen based on their description of real world examples and elaborate description of the methods applied in systems engineering.

3.2.2 Certainty, uncertainty and risk

Before the human factor can be taken into account certainty, uncertainty and risk have to be elaborated. Since the research is executed from a contractor's perspective in infrastructure, the articles about risk should consider the same perspective. Since the hypothesis specifies the design process and assessment of risk as problematic, literature about the role of certainty, uncertainty and risk in the design should also be considered.

For this research, articles from the association for project management (Norris, Perry, & Simon, 2000), a professor construction economics (Raftery, 2003), a professor integral design in civil engineering (De Ridder, 2013), an assistant Professor, Civil, Environmental and Architectural Engineering (Molenaar, 2005), the department of mechanical design and aerospace engineering (Matsumura & Haftka, 2013), and from a risk and Safety Group and a center for Infrastructure Performance and Reliability (Faber & Stewart, 2003) will be taken into account. This literature assesses the principles of actors in multiple disciplines, from design to safety, in multiple markets, from infrastructure to aerospace. The literature on infrastructure can thereby be supplemented or improved by literature from other divisions.

By doing so, an overview of risk and risk management in construction and the associated design process can be provided while considering approaches from multiple viewpoints differing from professors to project management associations.

4. Different approaches for designating problematic processes

This chapter describes different approaches of the problems that occurred during the cases. The first approach is based on a standard process and focusses on the deviations from this process for all the cases. The second approach is based on potential causes for failure costs suggested by literature and whether these causes occurred in the course of the cases.

The fact that two approaches are used helps in substantiating the processes in which proceedings with requirements led to failure costs. The problematic processes can be compared to the result of the analysis for potential causes for failure costs and thereby substantiating the findings. The two approaches however are not conclusive, the analysis can be expanded to the level of communications, differences in project management structures, the level of experience of the employees, organization management, etc.

The focus of the hypothesis however makes the use of only two methods valid.

4.1 A problematic process approach based on a standard process

The standard process will be described based on information from the internal project management system of Boskalis Nederland. In order to make the process comprehensible, a standard and academic method will be used which is abstracted from the US department of defense and the IDEFØ methodology. Both are elaborated next.

4.1.1 Department of defense

According to the US Department of Defense the analysis of requirements is a process which is controlled by an enabler who analyzes requirements and regulations in the form of inputs and controls, as can be seen in Figure 4.

- **Inputs converted to putputs:**
  - Customer requirements
  - Mission and MOEs (MNS, ORD)
  - Maintenance concept and other life-cycle function planning
  - SE outputs from prior development efforts
- **Controls:**
  - Laws and organizational policies and procedures
  - Military specific requirements
  - Utilization environments
  - Tech base and other constraints
- **Enablers:**
  - Multi-disciplinary product teams
  - Decision and requirements database including system/configuration item descriptions from prior efforts
  - System analysis and control

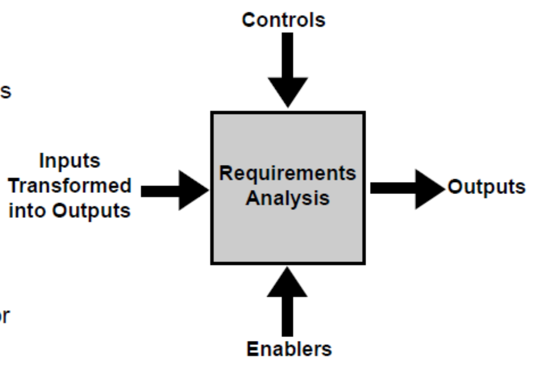


Figure 4 – Inputs for requirements analysis (US Department of Defense, 2001, p. 37)

The image above shows a process according to the United States department of Defense. The box on the right functions as a process in which inputs are introduced. The inputs are processed by the process which is influenced by the controls and the enablers, leading to output. The various possible characters of inputs, controls and enablers can be seen on the left.

For this research, the controls, as stated by the US Defense, are regarded as the sub processes which are needed for the process. The enablers are described as the employees responsible for the process. For example, the process manager (enabler) is responsible for the execution of systems engineering (control) in the project organization (process) based on the tender plan (input), eventually leading to a systems engineering tool (output).

4.1.2 *IDEFØ*

It is written in the federal information processing standards publications that the Integration Definition for Function modeling, shortly IDEFØ, is a model for developing structured graphical representations of a system or enterprise. The use of this standard permits the construction of models comprising system functions (activities, actions, processes, or operations), functional relationships, and data (information or objects) that support systems integration (Federal Information Processing Standards Publications, 1993, p. 1). The syntax for the method is visualized in Figure 5.

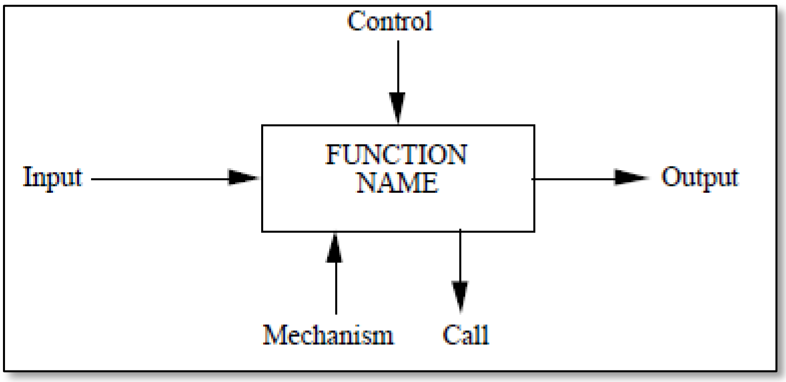


Figure 5 – Arrow positions and roles according to IDEF0 (Federal Information Processing Standards Publications, 1993, p. 11)

The image above shows the syntax for a process description as described by the IDEFØ standard. Boxes represent functions that show what must be accomplished. A function name must be an active verb or verb phrase. The arrows identify data or objects needed or produced by the function. Each arrow must be labeled with a noun or noun phrase (Federal Information Processing Standards Publications, 1993, p. 12). The terms input, control and output are the same as in the theory by the US department of defense, the enabler however is called a mechanism. Furthermore a call is added to the visualization. The call arrow enables the sharing of detail between models (linking them together) or between portions of the same model. It will however not be used for this research.

The description of the modeling technique from the US department of defense and the modeling technique from the federal information processing standard both show the human influence on the process and simultaneously take into account the controls. The only difference between the techniques is the application of the call arrow in the IDEFØ method. The call arrow can be used for sharing detail between models (Federal Information Processing Standards Publications, 1993), but for this research, this has no advantage. Hence, the modeling techniques above will be used without inclusion of the call arrow.

4.1.3 *The standard process for a project used by Boskalis Nederland*

Since the modeling technique is now known, the process from requirement specification to completion according to Boskalis Nederland can be visualized. In order to do so, information from the Intranet of Boskalis Nederland will be used. The intranet shows a visualized project management system taking into consideration the inputs and outputs per step in the process. The responsible employee can also be found on the intranet. Broadly, a difference can be made in a tender phase and a realization phase. The tender phase consists of the preparation of the bid for trying to win the project. The realization phase consists of the preparation and execution of the project. The process is visualized in Figure 6.

As described in paragraph 2.1 and 2.4, it is important to understand that this visualization describes processes, not proceedings with requirements. Proceedings with requirements are defined as the human influence in the process. Proceedings with requirements which are incorporated in this research are for instance interpretation of the requirements, translation of requirements and therefore decision making, assumptions on requirements, etc. proceedings can be defined as the influence of the employees (mechanisms) on the controls and process.

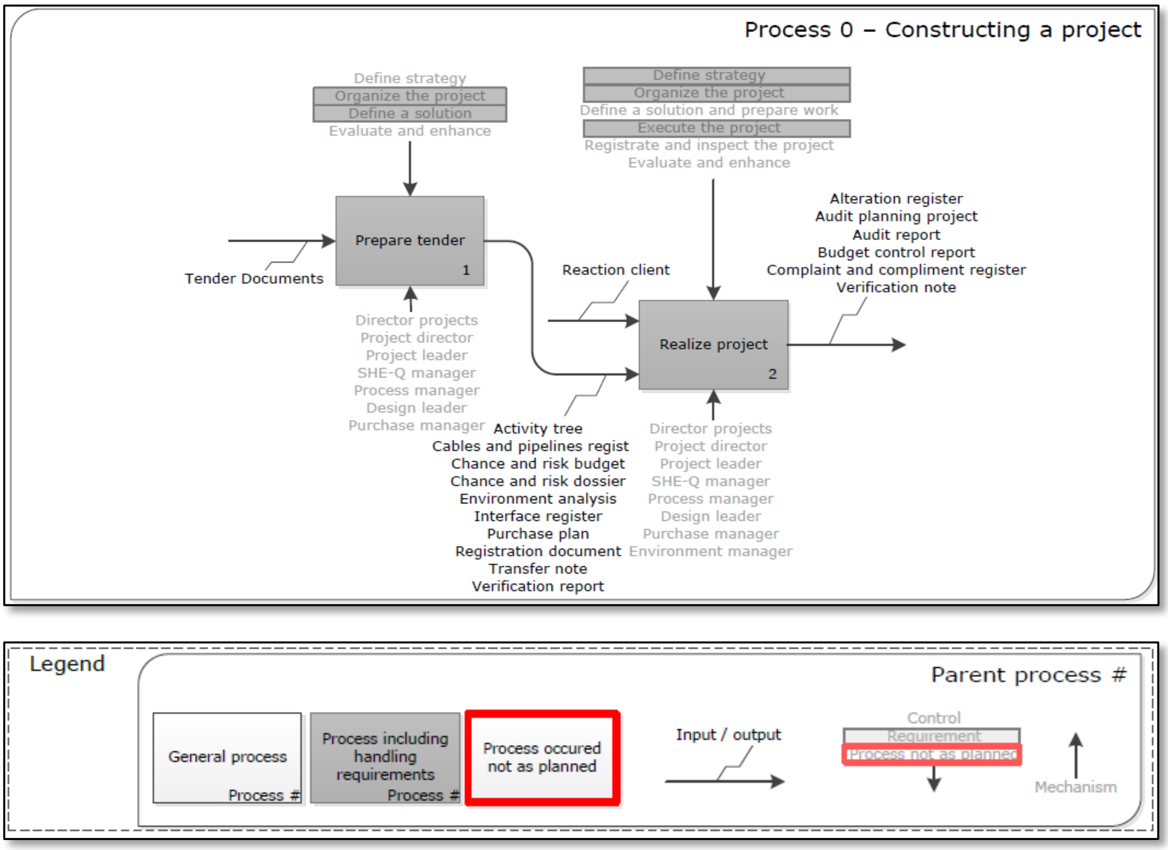


Figure 6 – The visualization of the construction process according to Boskalis Nederland (own ill.)

The image which can be seen above describes the process from requirement specification to completion of a project according to Boskalis Nederland visualized with an IDEFØ modeling technique which is described in paragraph 4.1.2. Both the preparation for the tender (box 1) and the realization of the project (box 2) include proceedings with requirements, so both processes are highlighted.

For a more elaborate description of this figure, Appendix II – Explanation of figures can be consulted.

The preparation of the tender and the realization of the project can be divided into multiple sub processes, which are already described as controls in Figure 6. When these processes are also visualized, the image which can be seen in Figure 7 describes the tender process and the image describing the realization process can be seen in Figure 8.

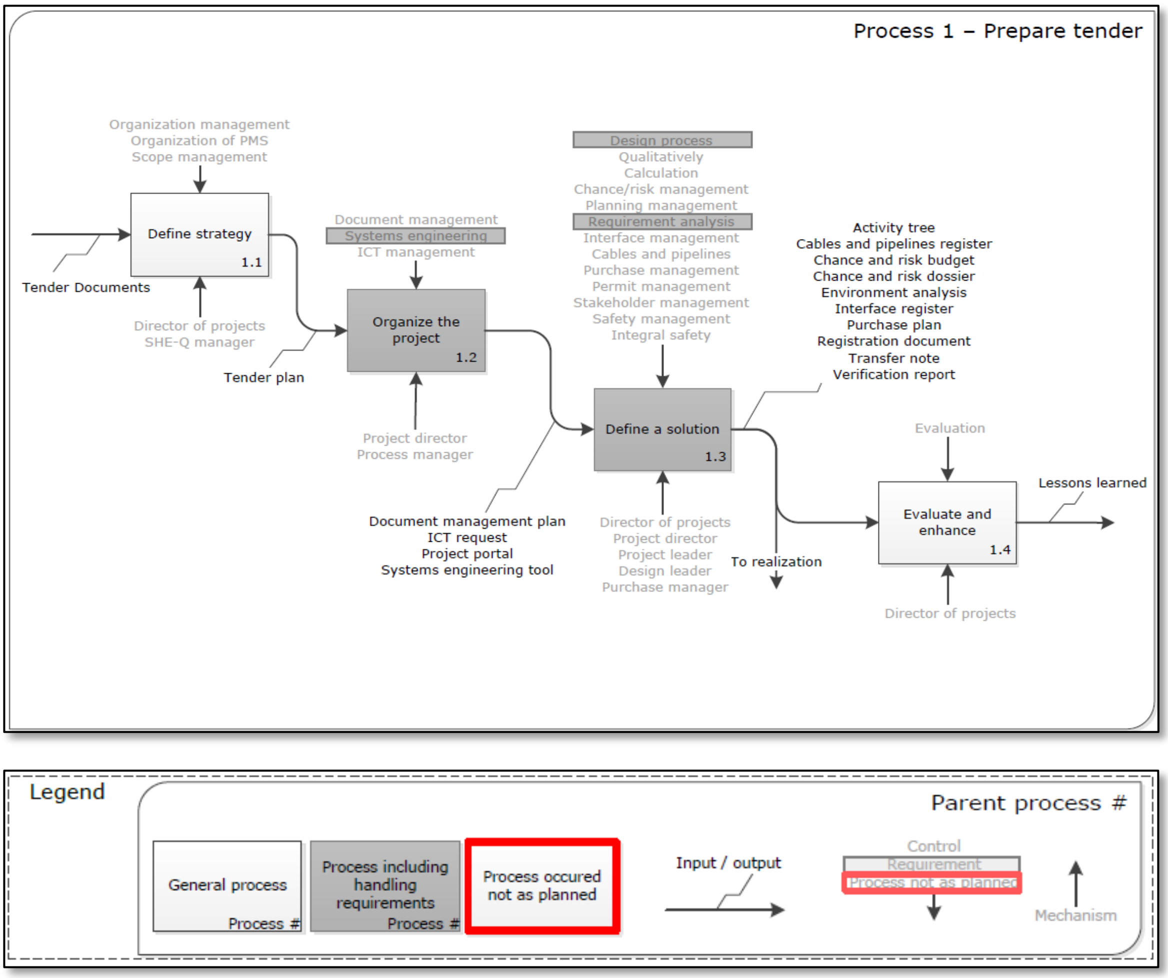


Figure 7 – The visualization of the tender process according to Boskalis Nederland (own ill.)

The image above shows the sequence of the steps taken in the tender the process from requirement specification to filing the tender according to Boskalis Nederland visualized with an IDEFØ modeling technique. The organization of the project (box 1.2) and the definition of a solution (box 1.3) are processes which include proceedings with requirements.

For a more elaborate description of this figure, Appendix II – Explanation of figures can be consulted.

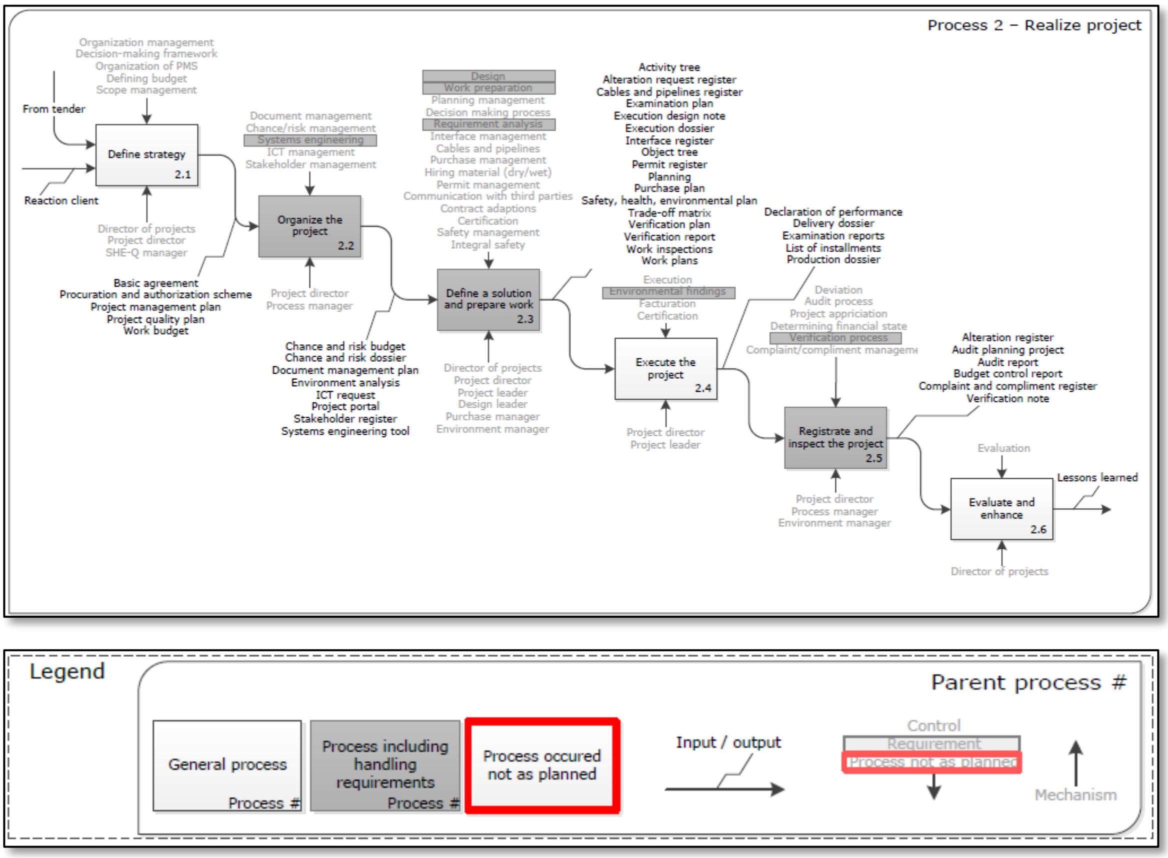


Figure 8 – The visualization of the process according to Boskalis Nederland (own ill.)

The image above shows the sequence of the steps taken in the realization process from award of the tender to completion of the project according to Boskalis Nederland visualized with an IDEFØ modeling technique. The organization of the project (box 2.2), the definition of a solution and preparation of the works (box 2.3) and the registration and inspection of the project (box 2.5) are processes which include proceedings with requirements.

For a more elaborate description of this figure, Appendix II – Explanation of figures can be consulted.

When the process proves to entail all steps which are needed for completion of a project by means of validation, the process can be used for this research. When the process proves to contain errors to begin with, a potential reason for failure costs emerges immediately.

4.1.4 *Validation of the Boskalis Nederland process*

The problems that occur in the projects can originate as a result of deviation from the intended process, but the proposed process itself can have its flaws as well. If the standard processes described above are used for checking whether the actual processes from the cases occurred as planned, the standard process may not contain any errors. Therefore the standard process according to Boskalis Nederland has to be validated.

The standard process for the validation is divided into a process and its controls, and output. The input is not considered since it is not part of the contractors responsibility and therefore of the scope of this research. The influence of the mechanism, or the employee, is not considered, since this is an organizational aspect, rather than a process based aspect.

Since the scope of the research focusses on processes which contain proceedings with requirements, the process is validated based on completeness of the processes with requirements. System oriented contract management by Rijkswaterstaat, a large client in infrastructure construction, will be considered. Systems engineering will be considered in validation of the process boxes since systems engineering is a problem solving approach in which requirements are translated into system elements (US Department of Defense, 2001, p. 32). Finally, theory on project management by De Ridder in combination with system oriented contract management, which is an approach used by the Dutch government, will be considered for determining the essential outputs. This way, the principles of multiple actors are assumed, creating an overview of the essential aspects for the process.

An elaborate description of the systems engineering approach can be found in paragraph 6.2. The systems engineering approach describes the processes with requirements from requirement specification to completion. The processes which occur in the systems engineering approach first focus on requirement decomposition and design in which multiple iteration steps take place in the form of validation and verification. After the design is finished, the project is executed. (US Department of Defense, 2001) (Wasson, 2006) (INCOSE, 2006)

For determining the essential output for a process, a system oriented contract management approach is elaborated. In this approach, Rijkswaterstaat describes the process of control of the contract and therefore the process of control of the requirements. The focus of Rijkswaterstaat is on evaluation, testing and verification of the requirements, as can be seen in Figure 9.

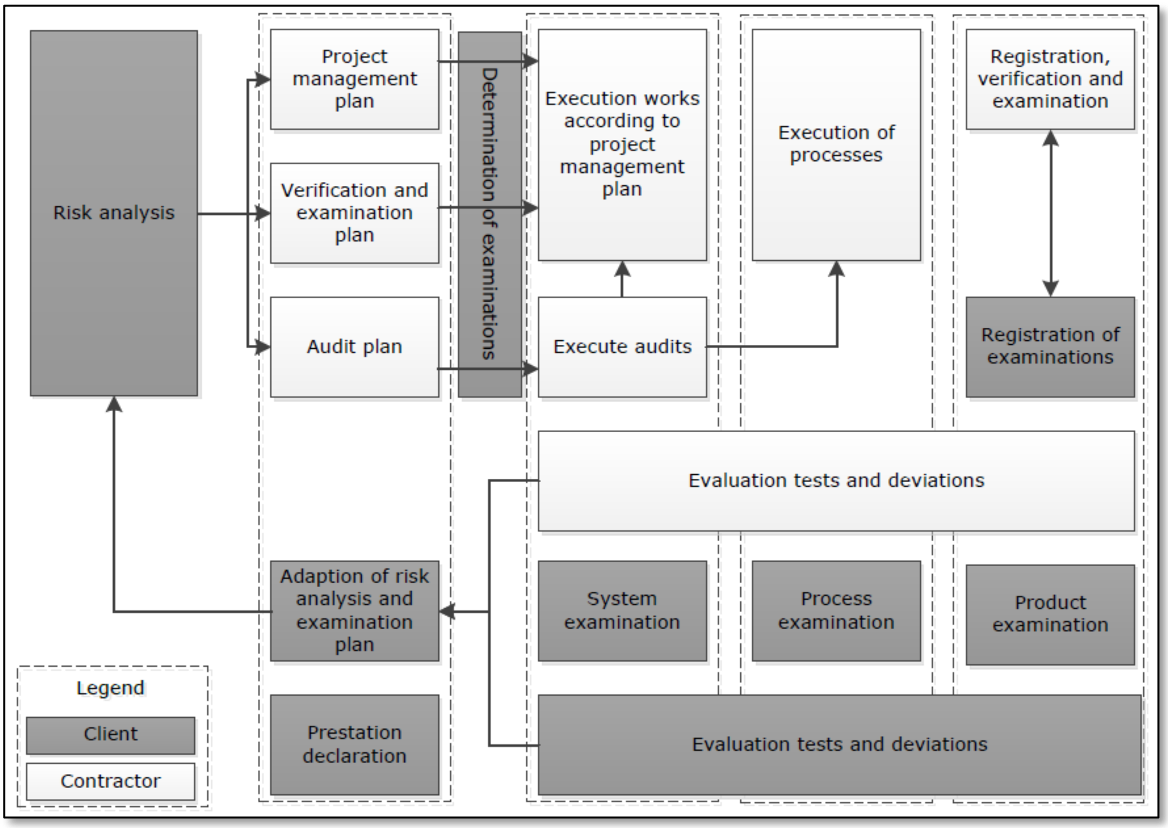


Figure 9 – System oriented contract management according to Rijkswaterstaat (own ill. based on (Rijkswaterstaat, 2011))

The image above shows the process of system oriented contract management as described in the system oriented contract management guide by Rijkswaterstaat. The purpose is to make sure the project is executed as is wished by the client. In order to do so, the process above is divided into responsibilities for the contractor in the white boxes and responsibility for the client in the dark grey boxes. The contractor has to *provide a project management plan, a verification and examination plan and an audit plan. Based on these plans the contractor starts to execute the project and execution of the associated processes, both of which have to be audited internally. Furthermore, the contractor is responsible for verification and examination of the project as defined in the plans. During the execution, which is visualized in the most right three dotted rectangles in the figure, evaluation of the examinations and deviations should take place.*

The client is responsible for a risk analysis on the plans of the contractor and the determination of a mix of examinations. Based on the results of these examinations, the risk analysis is adapted, just as the examination mix.

Rijkswaterstaat describes the project management plan, verification plans and audit plans as essential inputs. The execution of multiple processes then have to be audited, evaluated, and verified (Rijkswaterstaat, 2011). According to De Ridder, the requirements should lead to a plan in which schedule, budget and quality are controlled in the form of a planning, calculation and a design (De Ridder, 2013, p. 13).

The essential processes, controls, and outputs resulting from these descriptions above now have to be allocated in the standard process. A summation of the processes and controls described above and the allocation of them in the standard process can be found in Table 2.

Essential processes/ Controls	**Box/ control**	**Essential outputs**	**After Box**
Systems engineering	1.2/2.2	Budget calculation	1.3
Calculation	1.3	Planning	1.3/2.3
Planning management	1.3/2.3	Design	1.3/2.3
Requirement analysis	1.3/2.3	Verifications	2.5
Design	1.3/2.3	Audits	2.5
Verification	2.5	Project management plan	2.1
Auditing	2.5		

Table 2 – A summation of essentials for a description of a standard process based on different approaches.

The table above shows the essential processes and controls as a result of the systems engineering approach. On the right a summation of essential outputs is described. Both will aid in validation of the standard process. Both are allocated in or after boxes from the standard process which can be seen in Figure 7 and Figure 8.

Since all the essential processes, controls and outputs occur or are generated in the standard process, the requirement aspect of the process is validated. It can now be used to analyze the processes at the cases. When processes appear not to have occurred as intended, the processes will be taken into account when defining the problematic proceedings with requirements.

4.2 A problematic process approach based on failure costs from literature

This paragraph describes the different kinds of failure costs and the parts of the process in which they emerge. The first paragraph is based on literature, the second paragraph categorizes failure costs as is needed for the embedded case study. This chapter focusses mainly on the literature which describes failure costs in the Dutch building industry considering ground, water and road construction. Literature on this industry is chosen since this is the market in which Boskalis Nederland functions.

4.2.1 What are failure costs

In order to be able to define failure costs, the concept cost of quality (COQ) should first be explained. There are numerous methods which describe frameworks for calculating cost of quality (Akintoye & MacLeod, 1997) (Barber, Graves, Hall, Sheath, & Tomkins, 2000) (British Standards Institute, 1990) (British Standards Institute, 1992) (Ittner, 1988) (Ittner, 1989) (Tsai, 1998). These methods agree that the costs of quality can be divided into the following four categories:

1. Prevention costs
2. Appraisal costs
3. Internal failures
4. External failures

Prevention costs can be described as stopping non-conformance from occurring. These costs include education, training, etc. Appraisal costs are costs which stop non-conforming projects from being delivered. These are costs for internal examinations, verifications and grading to ensure specifications and requirements have been met. Costs of quality resulting from internal failures are costs for change in the design due to design errors or for repairing defective projects. Also compensation for delays in delivery is considered as an internal failure cost. External failures are costs which occur after delivery of a project to the customer. These are for instance – costs of repairs, returns, dealing with complaints and compensation. (Barber, Graves, Hall, Sheath, & Tomkins, 2000, p. 481)

From here the definition of cost of quality and failure costs can be derived. It is important to notice that the categories for costs of quality are merely categories with costs made in order to prevent problems with quality, not the costs made to ensure the quality.

Failure costs are described as costs of quality due to internal and external failures that exceed the costs needed to prevent them. This definition is based on a financial consideration, since it would be irrational to prevent events that have a lower financial impact than the cost made to prevent the event. Concluding, failure costs are contingent and could have been prevented by prevention costs which would have been lower than the costs for internal and external failure.

4.2.2 When do failure costs emerge

Failure costs are almost never directly designated to a single proceeding with a requirement. Therefore, interviews have been held by Bouwkennis among several actors in infrastructure construction in order to create insight in failure costs. Bouwkennis, a knowledge and network partner in construction focusing on delivering market information, divides the phases of a project into initiation, design, preparation, execution and delivery. The initiation phase is the responsibility of the client, delivering information about the project to be built. The design, preparation and execution are the major processes of the contractor in which the project is designed and build, eventually leading to delivery. The interviews of Bouwkennis are held with multiple functions and managers in the Dutch infrastructure construction industry and show that failure costs mainly originate in the design, preparation or execution phase, but the emerge in the execution (Bouwkennis, 2013) as can be seen in Figure 10 and Figure 11.

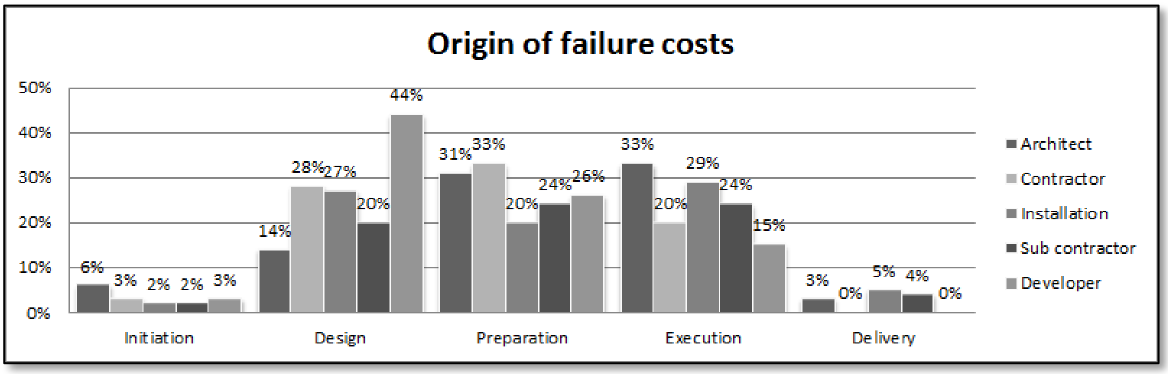


Figure 10 – The origin of failure costs (own ill. To Bouwkennis, 2013)

The bar chart visualizes the number of times a phase is indicated as the origin of failure costs as a percentage of the total number of interviewees. The graph is a result of answers by five different functions in the infrastructure construction industry, as can be seen in the legend. An important distinction which can be made in the graph is that the initiation and delivery phase are scarcely indicated as the origin of failure costs. The design, preparation and execution phase however are indicated much more as the origin of failure costs.

The expression and therefore the reveal of failure costs made in the design, preparation or execution, according to the interviewed, almost always occurs in the execution phase, as can be seen in Figure 11.

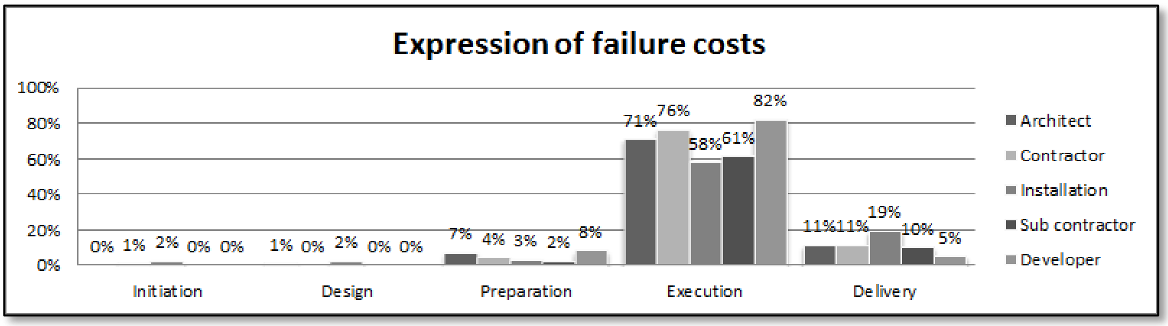


Figure 11 – The expression of failure costs (own ill. To Bouwkennis, 2013)

The bar chart above shows the number of times the interviewees have designated a project phase as the phase in which failure costs are expressed as a percentage of the total number of interviewees. It is evident that the execution is designated as the phase in which most failure costs are expressed.

This information should be taken into account when considering the projects to be analyzed. The projects at least have to be in the execution phase in order to be able to pinpoint the failure costs. The origins for failure costs cannot be analyzed when the expression is not yet certain.

From these figures we can conclude that the most interesting phases to consider for the research are the design, preparation and the execution phase since these phases result in the majority of the failure costs according to the interviewees.

4.2.3 Causes for failure costs

There are numerous reports describing failure costs in the Dutch infrastructure construction industry. The causes for failure costs from these reports will be summed up and analyzed in order to be able to compare the cases with the potential causes for failure costs.

Bouwkennis again bases the causes for failure costs on the responses to the interviews and therefore on expert opinions. There is a strong disunity about the origin of failure costs. Developers and contractors believe that failure costs mainly emerge in the design phase and less in the execution phase. Architects, installers and sub-contractors believe the opposite to be true. According to Bouwkennis, an explanation can be found in the fact that architects do not acknowledge that flaws in their designs are responsible for failure costs and that they will point towards other parties. The rest of the functions do the same, making the highly phased construction process vulnerable for errors. (Bouwkennis, 2013)

The most important reasons for failure costs according to Bouwkennis are design errors, problems in work preparation, errors in the planning, problems in delivery, communication problems and complexity of the project (Bouwkennis, 2013). Another investigation of

Bouwkennis designates an impracticable design and communication flaws as the most important causes for failure costs (Bouwkennis, 2008).

The economic institute for construction suggests that failure costs are the result of a lack in incentive for measures against these failure costs. The origin for this lack of incentive is placed at ineffective project management, impracticable design, and deficient communication (Koning & Van Elp, 2011).

USP Market Consultancy suggests that failure costs are the result of inadequate work preparation, a lack of incentive to control the project based on a strong contract, inadequate communication, and also an impracticable design (USP Marketing Consultancy bv, 2008). A later research adds the lack of evaluation and therefore adequate project governance as a major factor for failure costs (USP Marketing Consultancy bv, 2010).

The construction industry group from PriceWaterhouseCoopers (PWC) also suggests that impracticable design and communication flaws are the main causes for failure costs. They also state that the origin of these causes lie in the increase in project size. (PWC, 2010).

An international research by PWC comes up with a summation of ineffective project governance, management and oversight, unanticipated site conditions, late design/ poor project definition, inadequate communications and slow decision making, weak/ambiguous contract terms and lack of incentives to control costs, an ineffective decision-making process, poor risk identification, management and response strategy, imposed cash constraints and delayed payment, skilled labor availability, an inexperienced management team, design errors and omissions leading to scope growth and/or re-work, poor project controls (cost & schedule) and insufficient planning, and inadequate estimating as causes for failure costs (PWC, 2013). The causes for failure costs summed up in the research are based on capital projects in general.

The causes for failure costs which will be taken into account for the research can be seen in Figure 12. The potential causes for failure costs figure will be compared to the courses of the cases. When the problems in the cases match the potential causes for failure costs, the process will be taken into account for determining proceedings with requirements which are responsible for failure costs.

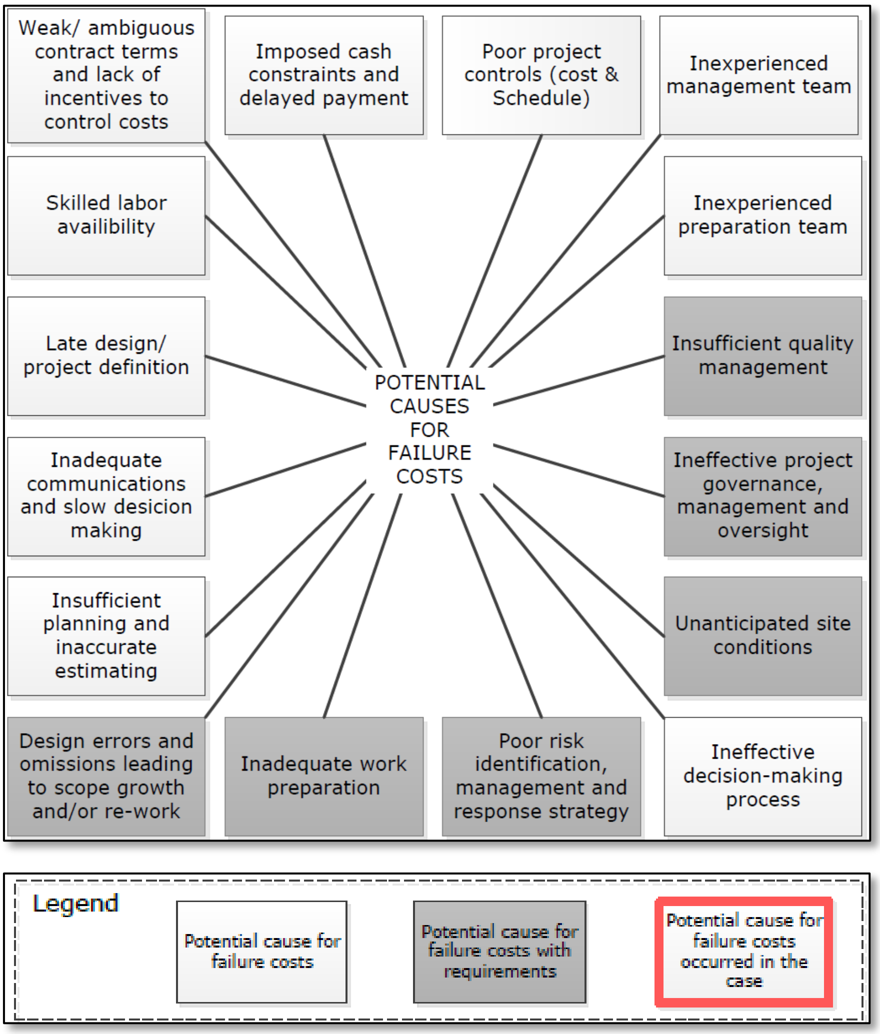


Figure 12 – Causes for failure costs according to literature (own ill.)

The image above shows the potential causes for failure costs according to numerous researches by Bouwkennis, the economic institute for construction, USP Market Consultancy, and PWC. The boxes which are highlighted are boxes which consider proceedings with requirements.

5. The result of both approaches

This chapter will provide information about the five analyzed cases by comparing the course of the cases to the standard process. Furthermore, the course of the cases will be compared to potential causes for failure costs.

In order for the cases to be comparable, selection criteria have been devised. The cases which are analyzed have been selected based on the contract type, size, phase they are in and the contribution of Boskalis Nederland in the project. The contracts had to be based on integrated approach in which the contractor was (partly) responsible for the decomposition of requirements and the design. Contracts that meet the description are engineering and construct contracts, design and construct contracts, design build and maintenance contracts, design build finance and maintenance contracts, etc. The size of the projects was considered based on its value and duration. Every project was classified in a range of project value and all projects had to be in a range of at least €10 million in order to be taken into account. The project duration had to be more than 2 years. All projects had to be far in the realization phase. This enabled the information from the tender and the preparation to be tested in execution, since this is where most failure costs emerge according to Figure 11. Finally, the contribution to the project by Boskalis had to be at least 50% in order to make sure that all proceedings analyzed were proceedings influenced by Boskalis. Based on these variables, a selection of five projects was made.

This selection led to projects in which the information would still be available and the employees would remember what has occurred at the projects. The size of the project was chosen to incorporate the organization in the analysis. The selection started with a list of 44 projects which was narrowed down by application of the selection criteria.

Information needed for the analysis of the cases was retrieved by conducting 26 interviews with employees of Boskalis Nederland. Per case a minimum of five interviews were held. For the interviews a standard set of questions has been drafted with the focus on revealing the course of the project and the most problematic events. The assembly of interviews per case allowed the preparation of a course of the project which was substantiated by internal documents for the project. The description of the course per case has been input for the analysis in this chapter.

The goal of this chapter is merely to designate the problematic processes and potential causes for failure costs. This is done based on case descriptions from interviews and project documents. The contents of the projects are restricted and merely accessible for Boskalis Nederland. The contents of the projects will therefore remain abstract throughout this report. This chapter will merely cite the problematic events and provide no detailed course of the cases.

At first all cases will be generally introduced and an indication of the result of the cases based on schedule, budget and quality will be provided per case. Then the comparison of the problematic processes and controls and the standard process is visualized. The influence of the mechanism will be considered later in this research. It is important to confirm the problem definition for all cases after the analysis in order to be able to draw conclusions.

5.1 Case 1

The first case to analyze is a project specifically designed for maintenance. The most important result of the tender phase consisted of the calculation of prices for maintenance works. Furthermore a description of the methods used by the contractor for the fulfilment of qualitative criteria posed by the client was submitted.

Once the project was awarded, the client defined the scope for the maintenance activities for that year which was then processed by the contractor. This process was repeated four times. As the project proceeded, unclear requirements were discussed with the client.

The result of this project was rather good, there were no major budget or time overruns and the quality of the project could often be verified.

5.1.1 *Process*

As described in the introduction, the realization phase occurred four times instead of only once, as is prescribed by the standard process. This deviation is attributable to the characteristic maintenance aspect of the case, since the maintenance had to be executed every year for four years in a row. Next to this, no major deviations from the standard process occurred, as can be seen in Figure 13. The preparation of the tender is followed by the realization of the project without interference.

After that, the tender phase and the realization phase are described in more detail in respectively Figure 14 and Figure 15. A short description of the deviations and the origin of these deviations is added in the description of the figures.

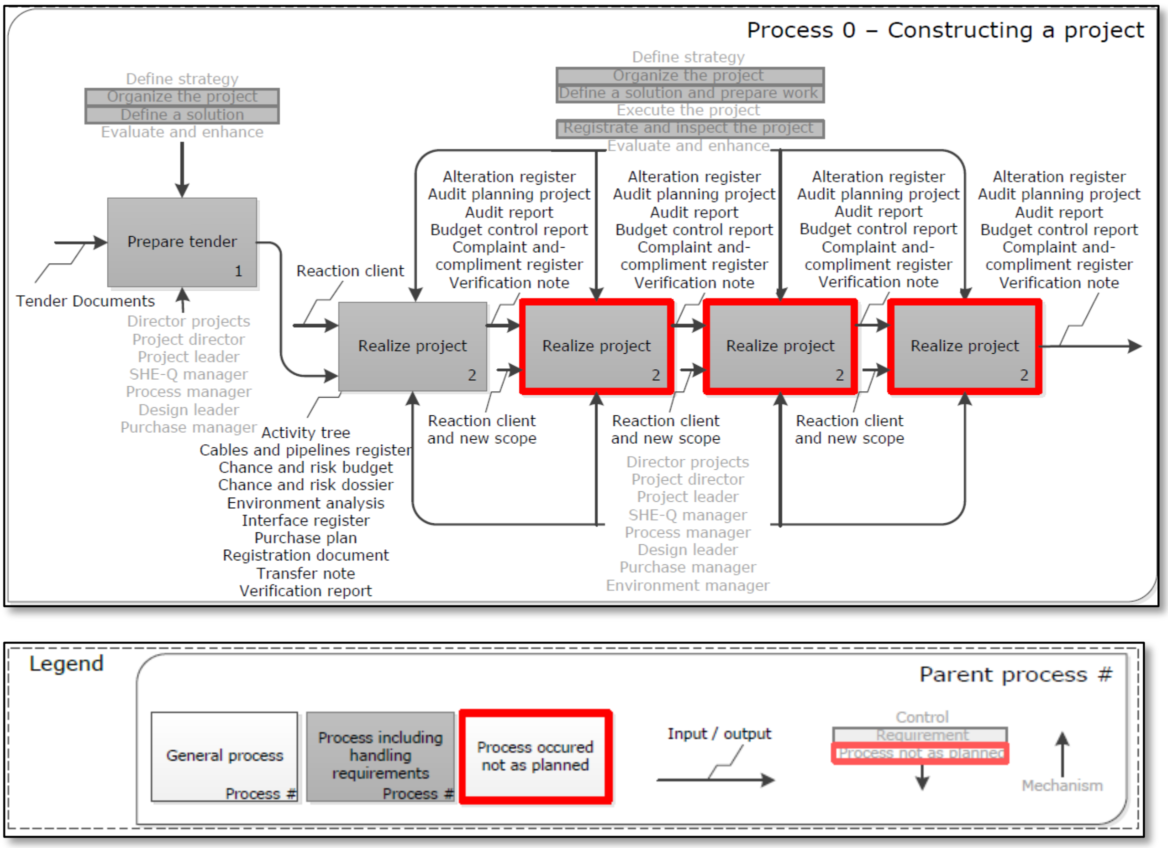


Figure 13 – Visualization of the construction process of case 1 (own ill.)

The image above shows the visualization of the construction process of case 1 in which the characteristic repetition of the realization phase can be seen. The processes which are delineated red are processes which have deviated from the standard process. This deviation is the result of the origin of the case; maintenance. Furthermore, no major alteration took place.

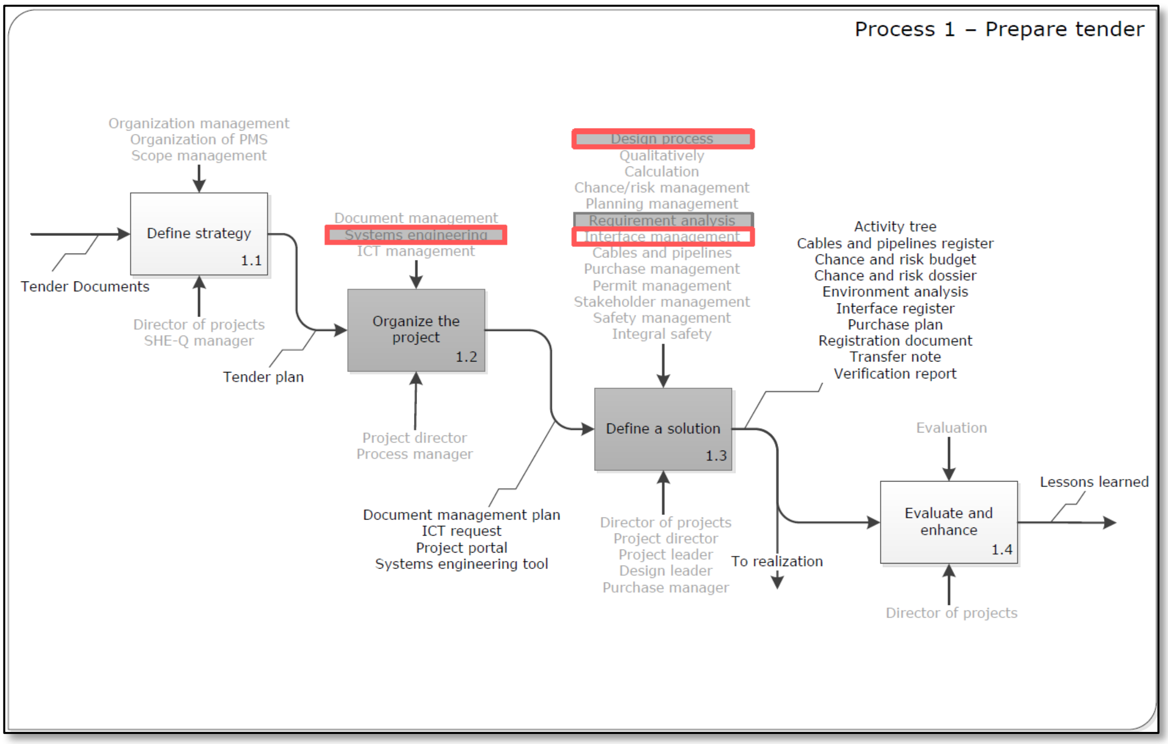


Figure 14 – Visualization of the tender process of case 1 (own ill.)

The image above shows the more detailed processes of the tender phase, in which we can distinguish deviations from the standard process delineated in red. As can be seen, there were no major deviations in the course of the tender, but there were some in the controls of the tender. Systems engineering was not applied in the tender phase and the design process was not necessary since a calculation of the maintenance prices was sufficient. Finally, interface management was also not applied in the tender phase.

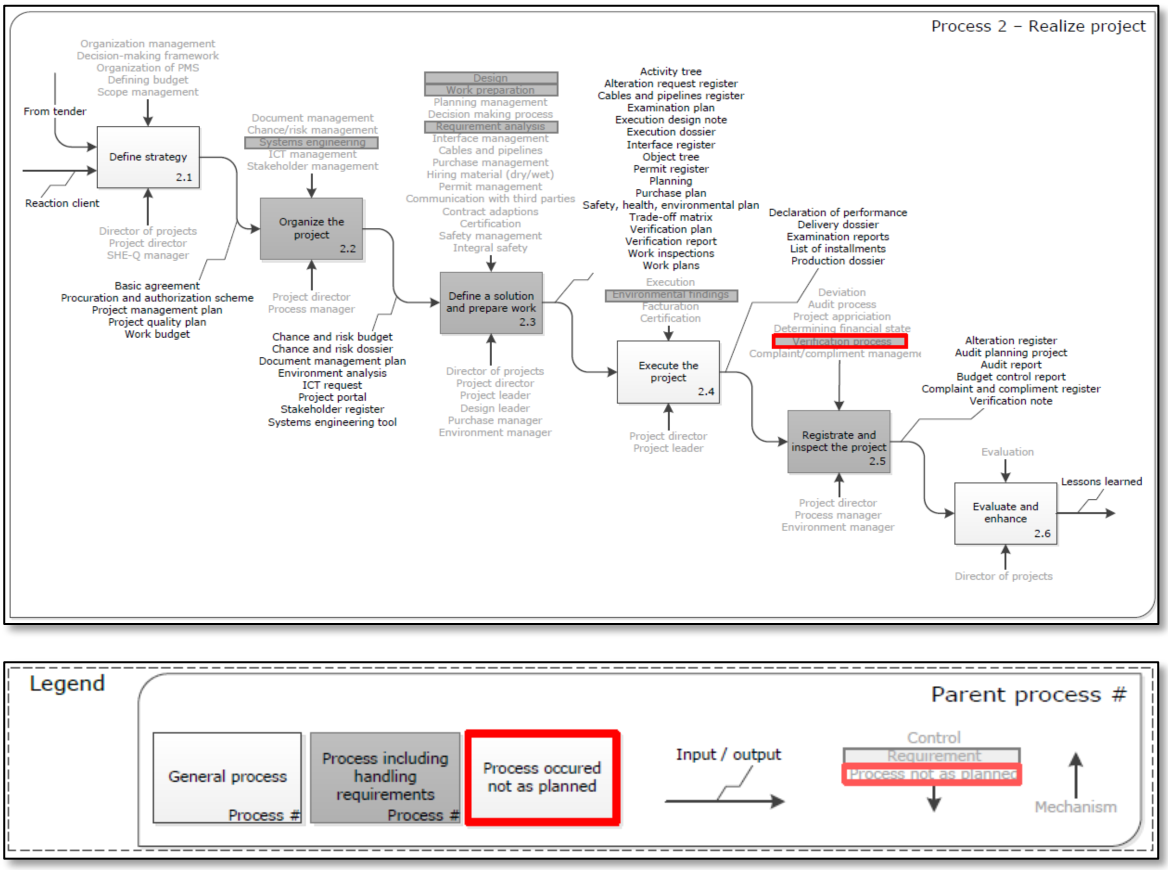


Figure 15 – Visualization of the realization process of case 1 (own ill.)

The image above shows the realization phase of the first case and the problems with it delineated in red. The only problem that occurred in this process is not in the course of the processes, but in the control responsible for verification. Proving the quality of the project towards the client by means of verification and examination has proven to be difficult.

5.1.2 *Failure costs from literature*

The visualization which can be seen in Figure 16 indicates which potential causes for failure costs from literature have occurred in the project.

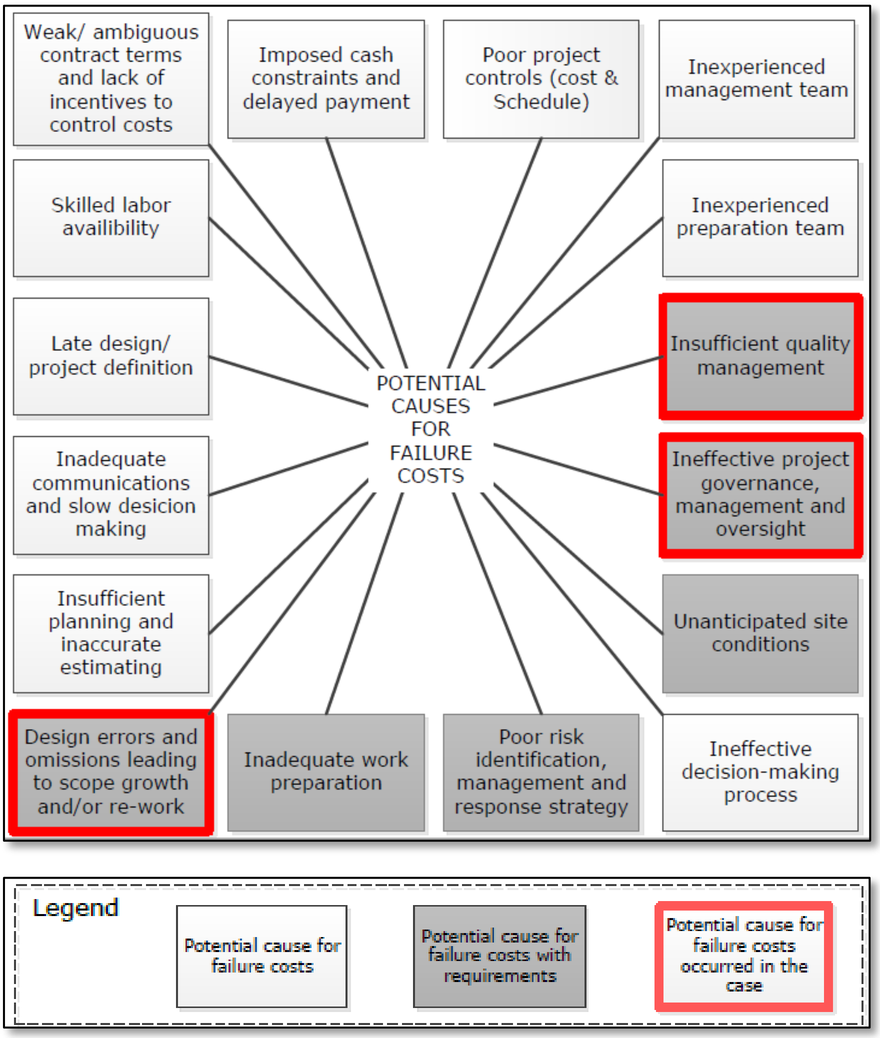


Figure 16 – Visualization of the potential causes for failure costs of case 1 (own ill.)

The image above shows the potential causes for failure costs from literature and delineated in red whether these causes were present at the first case. With the delineation of the box which contains ineffective project governance, management and oversight, it is implied that systems engineering was not applied in the tender phase, the fact that verification has proven to be difficult in delivery of the project results in the delineated box insufficient quality management.

With the delineation of the box containing design errors and omissions leading to scope growth and/or re-work, it is implied that the design in the tender phase, which was actually a calculation of the costs for maintenance, was not complete leading to higher maintenance costs for the contractor.

5.1.3 *Concluding*

Concluding, the deviation from the major standard construction process is attributable to the character of the project and is not the result of problems in the project. The repetition of the execution phase had been planned from the beginning, so the deviation from the standard process is valid. Some of the controls have not occurred as planned, but the majority of the project went according to plan.

As the description of this case mentions, the design in the tender phase, or the calculation, has not been as intended, leading to higher costs for the contractor which could have been avoided. Therefore, the problem definition is confirmed for this case.

5.2 Case 2

Case 2 consisted of a large infrastructural work with multiple civil structures. The client delivered a design of which the prize was calculated by the contractors. Once the project was awarded, the contractor started to detail the design, but after a while, the client retrieved its initial design due to unforeseen circumstances. In a collaboration between client and contractor, the design from the tender phase was created again which was now a substantiated base for the rest of the project. Unclear requirements were discussed with the client.

The result of this project was rather good. There were no major budget or schedule overruns. Verifying the quality of the project towards the client sometimes caused problems, but the majority of the verifications succeeded.

5.2.1 Process

An important alteration from the standard construction process is the step back into the tender phase, as can be seen in Figure 17. This was the result of problems which were the responsibility from the client.

The tender phase and the realization phase are described in more detail in respectively Figure 18 and Figure 19. A short description of the deviations and the origin of these deviations is added in the description of the figures.

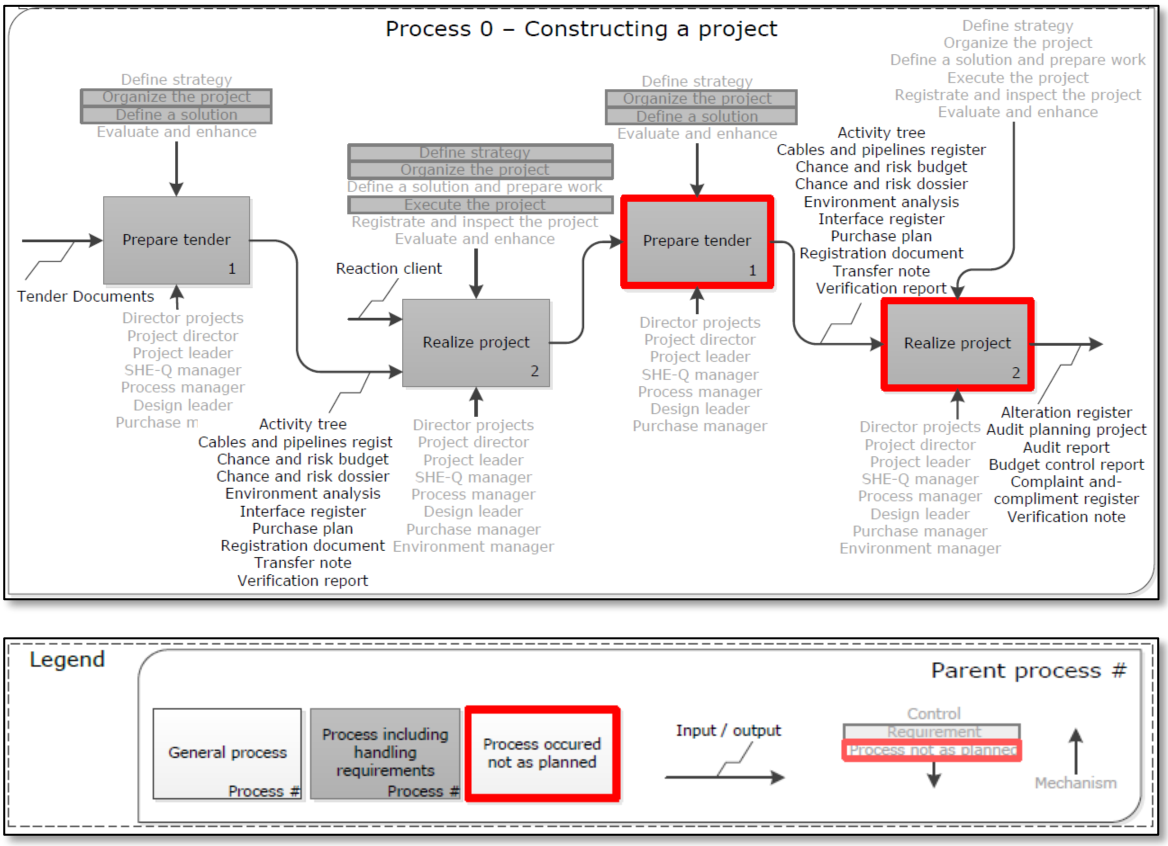


Figure 17 – Visualization of the construction process of case 2 (own ill.)

The image above shows the visualization of the construction process of case 2 in which the processes delineated in red are processes which have deviated from the standard process. It is interesting to see that during the realization phase, a step back had to be taken into the tender phase. As described above, the origin of this step back lies in the retrieval of the reference design by the client. After the client and the contractor collaboratively made a new preference design, the realization phase could start again.

The step back towards the tender phase did not result in a completely new tender, but merely in the production of new outputs.

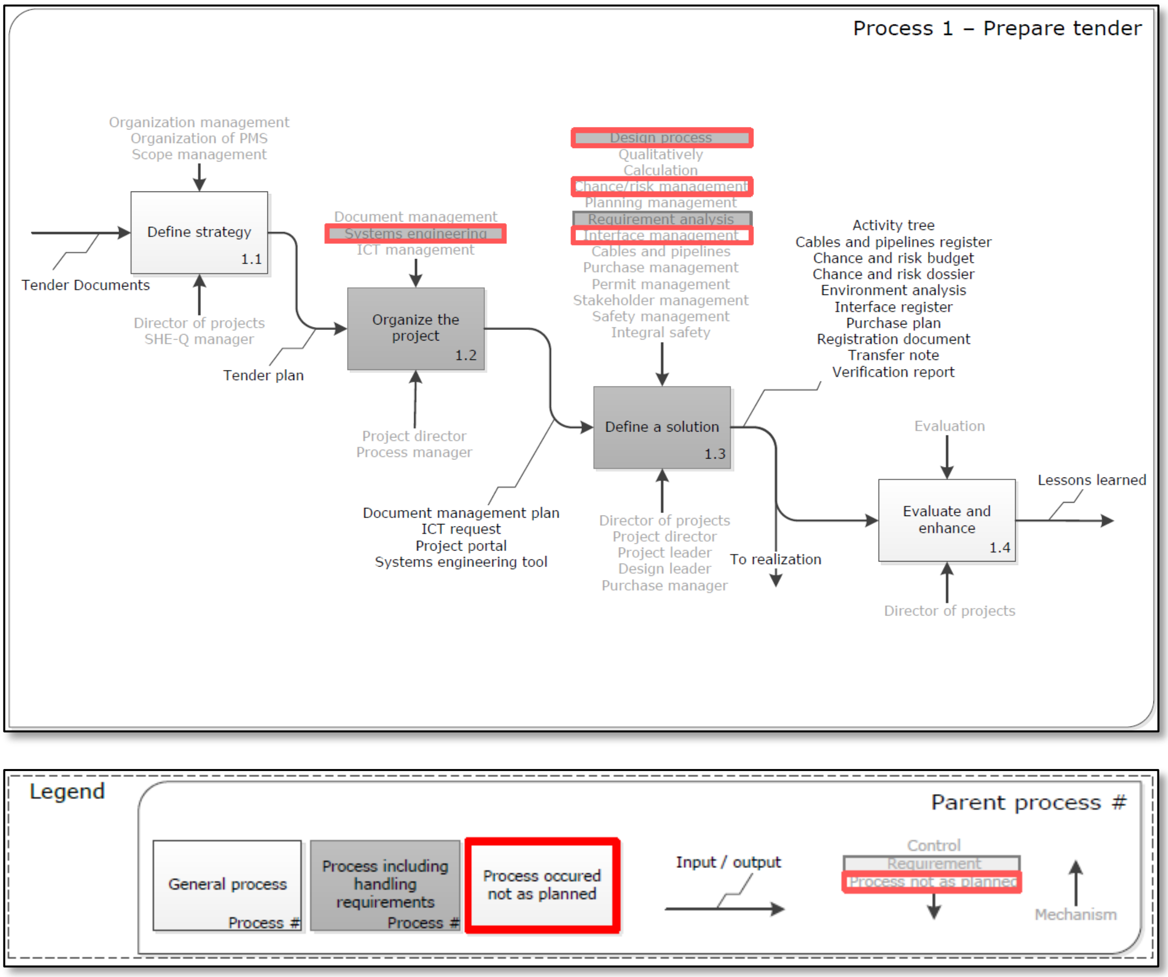


Figure 18 – Visualization of the tender process of case 2 (own ill.)

The image above shows the more detailed processes of the tender phase, in which we can distinguish deviations from the standard process delineated in red. The process itself has occurred as planned, some of the controls however have not been followed. As can be seen, systems engineering has not been applied in the tender phase. Furthermore, the design has expired different than planned, in particular because the original reference design had to be remade in collaboration with the contractor. This is not proposed by the standard process. Chance and risk management is an aspect which has not been executed in the tender phase, just as interface management.

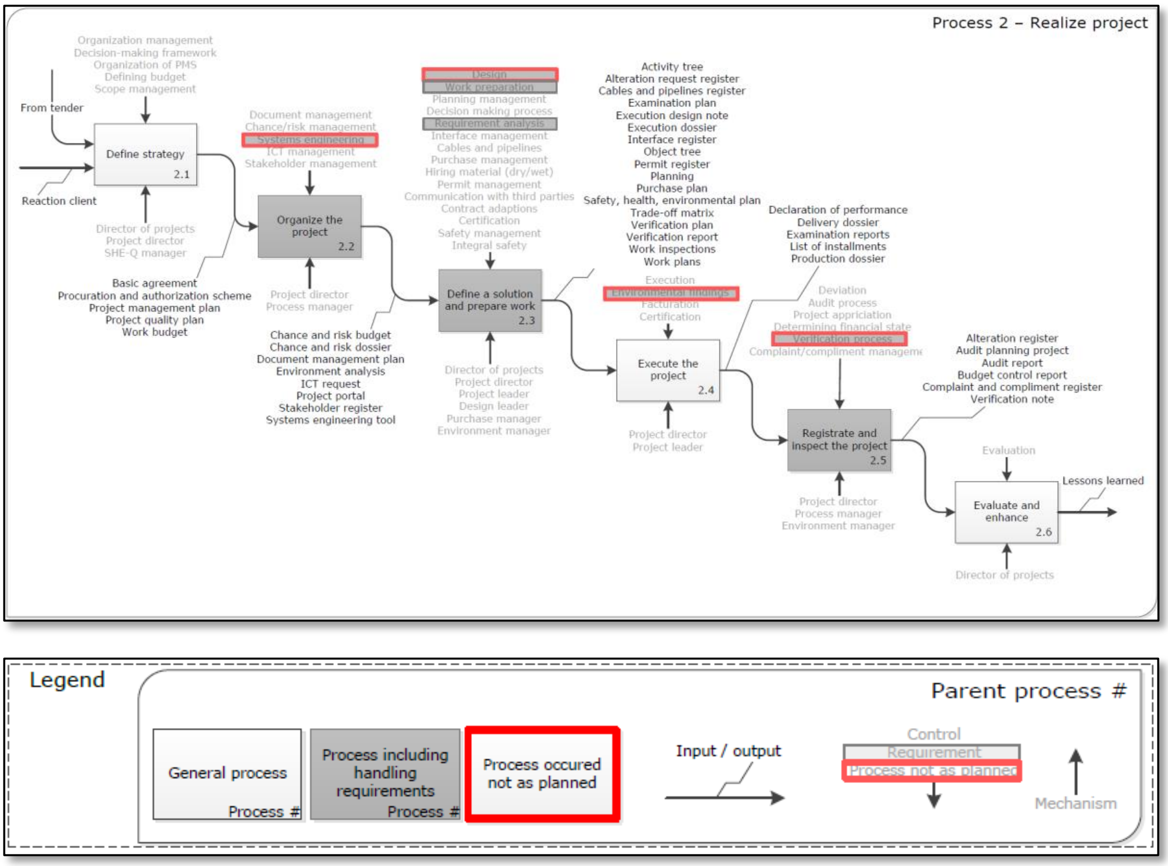


Figure 19 – Visualization of the realization process of case 2 (own ill.)

The image above shows the more detailed processes of the realization phase. Deviations from the standard process again are delineated in red. The process occurred as proposed, but some of the controls did not. Systems engineering for instance was not widely supported at the project and did not expire as planned since it was not an intrinsic process. The design and environmental findings also caused problems, mostly since the situation on site was different than assumed in the design resulting in adaptions in the use of soil. Finally, the verification process did not always occur as planned, sometimes resulting in problems in proving quality.

5.2.2 *Failure costs from literature*

The visualization which can be seen in Figure 20 indicates which potential causes for failure costs from literature have occurred in the project.

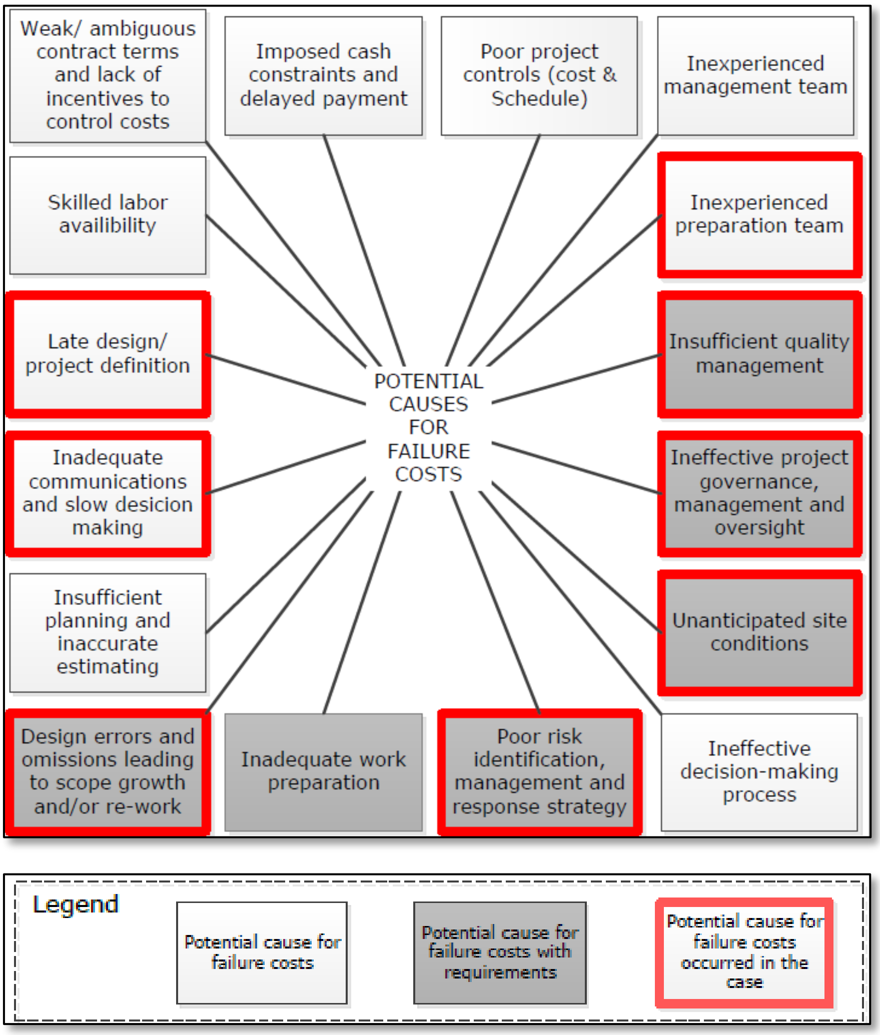


Figure 20 – Visualization of the potential causes for failure costs of case 2 (own ill.)

The image above shows the potential causes for failure costs from literature and whether these causes were present at the second case delineated in red. We can see that a lot of events took place in the project of which ineffective governance, management, and oversight is missing of systems engineering in the tender phase and problems with it in the realization phase. Unanticipated site conditions and design errors have a direct relationship. Risk identification, management and response strategy could have prevented the problems resulting from the differing site conditions. Inadequate communications occurred in the transfer from the preparation to the realization due to inexperience of the execution team and the realization team in working with integrated contracts. This resulted in a short standstill in the project. The late design was the result of the late release of land. The fact that verification has proven to be difficult in delivery of the project results in the delineated box insufficient quality management.

5.2.3 Concluding

Concluding, the deviation from the general standard construction process is attributable to client problems and not the result of problems in the project. Several controls have not occurred as planned, but the project eventually went according to plan. It is interesting to see that, even though a lot of potential causes for failure costs took place during the project, the result of the project is not that negative.

As the description of this case mentions, the design in the realization phase was not as eventually built due to an erroneous interpretation of the environment to build on. Furthermore, problems in communication of the design towards the execution led to short standstills which led to failure costs. The problems have led to higher costs for the contractor which could have been avoided. Therefore, the problem definition is confirmed for this case.

5.3 Case 3

This dike reinforcement project started with a design from the client which served as a reference design. The price for constructing the design was calculated and a planning was made accompanied by several realization plans. Once the project was awarded, the design was elaborated and construction could start. Requirements which were unclear were discussed with the client. The result of the project was fairly good and the costs of the project barely exceeded the budget.

5.3.1 Process

For this case, there is no deviation from the general process as described by the standard process, nor is there a difference in the occurrence of the controls. Therefore the tender phase is described directly in Figure 21.

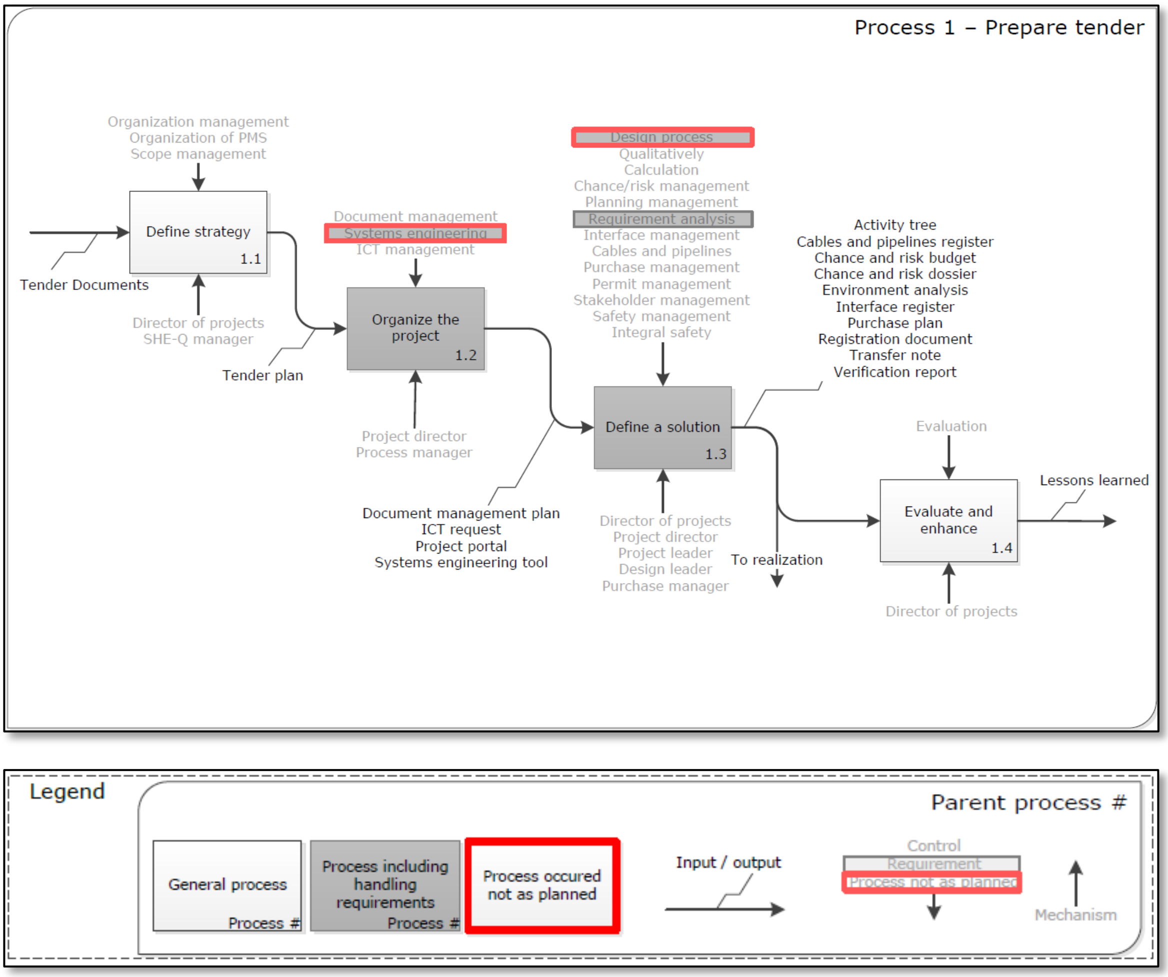


Figure 21 – Visualization of the tender process of case 3 (own ill.)

The image above shows the more detailed processes of the tender phase, in which we can distinguish deviations from the standard process delineated in red. Systems engineering has not been applied in the tender phase. The design control has not been executed, since the client already delivered a design which merely had to be prices and combined with a planning.

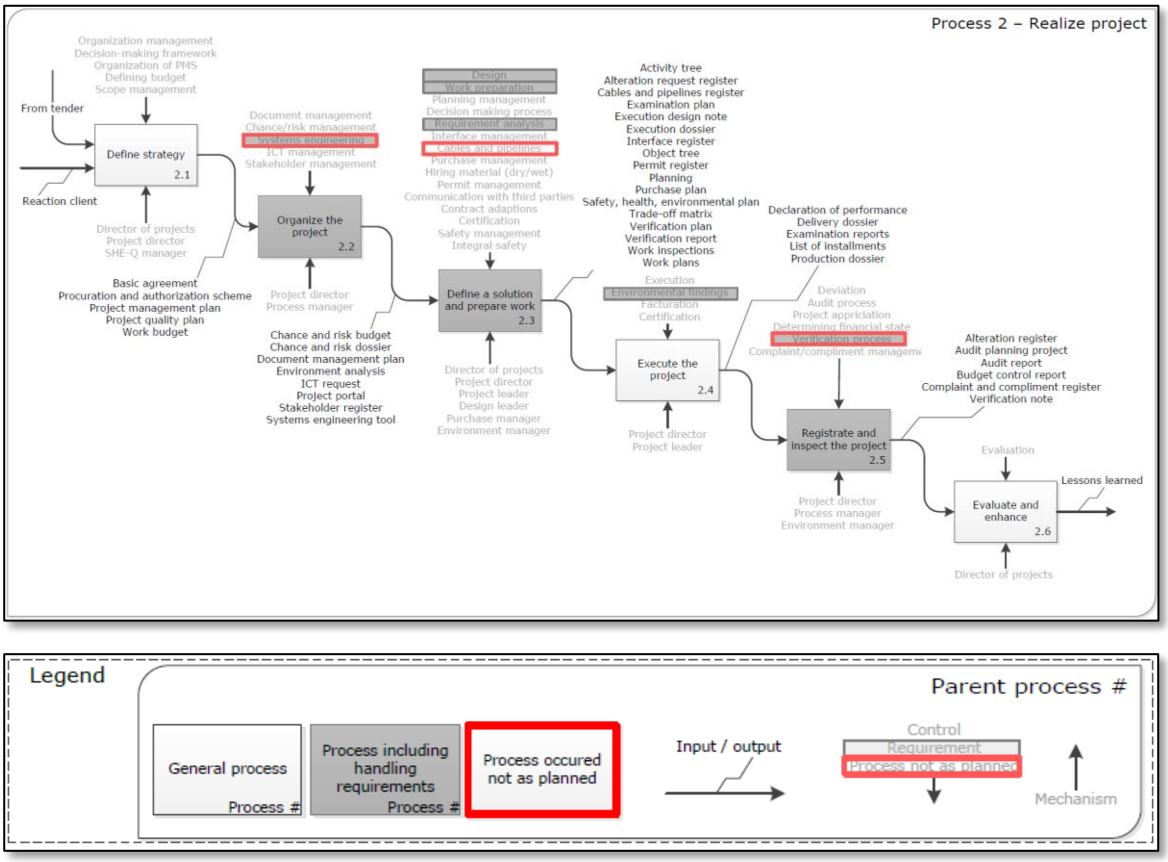


Figure 22 – Visualization of the realization process of case 3 (own ill.)

The image above shows the more detailed processes of the realization phase. Deviations from the standard process again are delineated in red. There have been some issues with systems engineering since this was not a methodology widely supported, also the verification process did not occur as planned. Furthermore, shifting cables and pipelines have caused some problems in this project

5.3.2 *Failure costs from literature*

The visualization which can be seen in Figure 23 indicates which potential causes for failure costs from literature have occurred in the project.

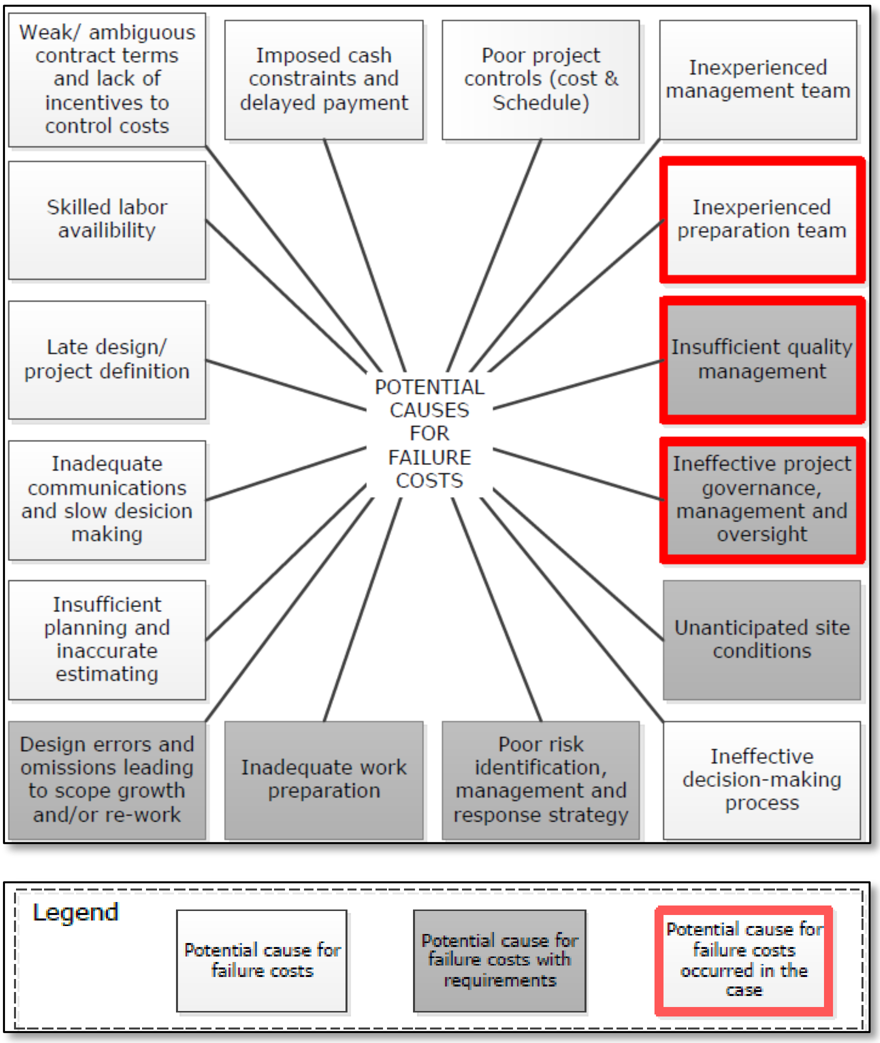


Figure 23 – Visualization of the potential causes for failure costs of case 3 (own ill.)

The image above shows the potential causes for failure costs from literature. When these causes were present at the third case the boxes are delineated in red. We can see that the team had little experience with a project alike and that ineffective systems engineering was applied. The fact that verification has proven to be difficult in delivery of the project results in the delineated box insufficient quality management.

5.3.3 *Concluding*

Concluding, there is no deviation from the standard process or in the tender or realization process and there are little potential causes for failure costs which occurred in the project. There are however some controls which have not occurred as planned. Systems engineering was not applied according to the standard process and verification has proven to be difficult at times.

As the description of this case mentions, there were some problems with verification of the quality of the project and the incorporation of removing cables and pipelines in the design. These problems have led to slightly higher costs for the contractor which could have been avoided. Hence, the problem definition is confirmed for this case.

5.4 Case 4

This case consisted of a large river control project which started with a reference design from the client which was accompanied by a planning and a plan of action. The contractor started detailing the design in the tender phase based on documents which were provided by the client. In the realization phase, the design was elaborated further into a design which was ready for execution. During the execution, it appeared that the design was based on elements which were not present at the site, so the work stopped and design had to be redone. Furthermore, discussion arose about the interpretation of several requirements by the contractor.

The project did not go as planned and the result was disappointing in budget and schedule.

5.4.1 Process

For this case, there is no deviation from the general process, nor is there a difference in the occurrence of the controls. Therefore the tender phase is described directly in Figure 24. The source of the realization phase can be seen in Figure 25.

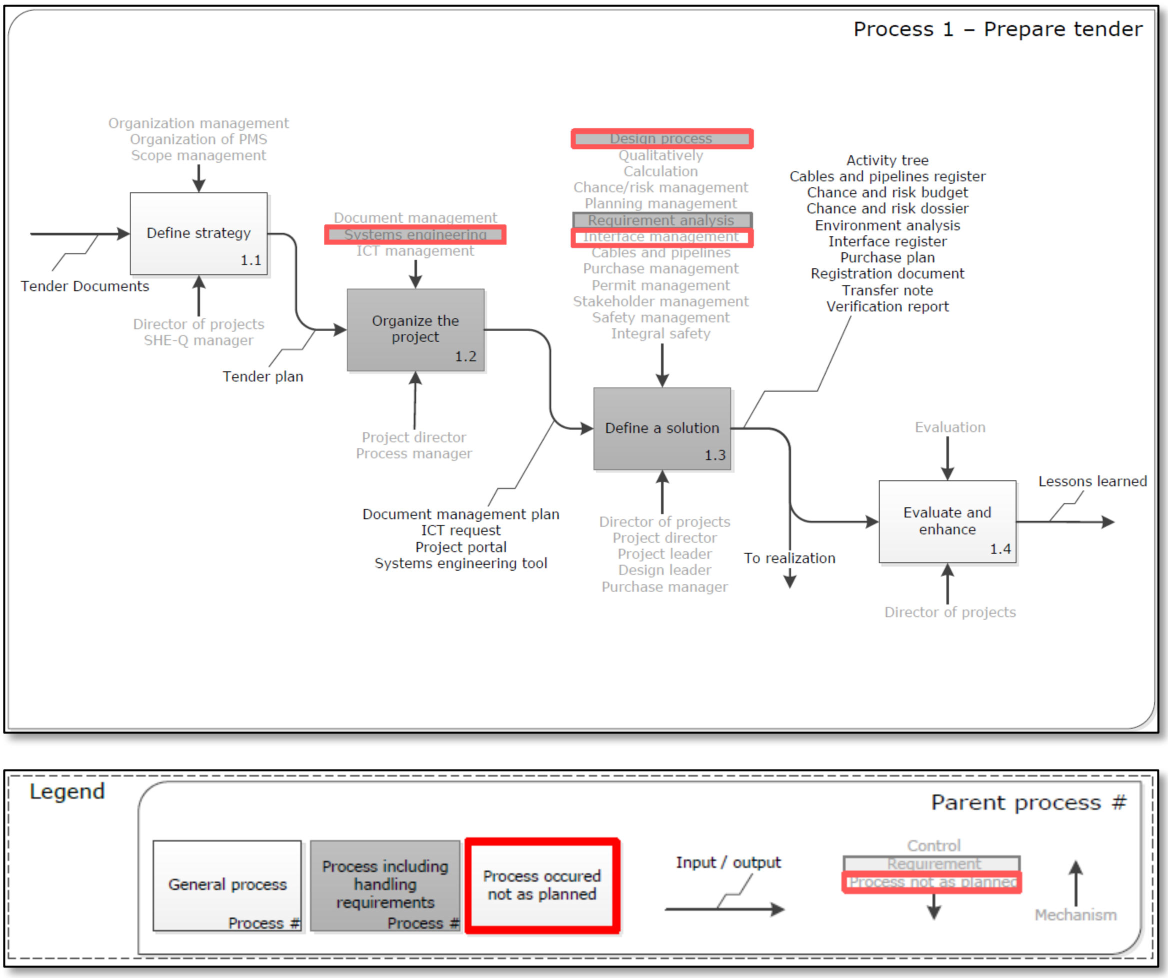


Figure 24 – Visualization of the tender process of case 4 (own ill.)

The image above shows the more detailed processes of the tender phase, in which we can distinguish deviations from the standard process delineated in red. We can see that the course of the tender phase has occurred as planned, but that some problems arose in the controls. Systems engineering was not applied as planned in the tender phase, since it was no widely supported. The design control was not executed as planned. The steps which should be taken for creating a design were mixed up and did not occur as standard. Finally, interface management was not applied in the tender.

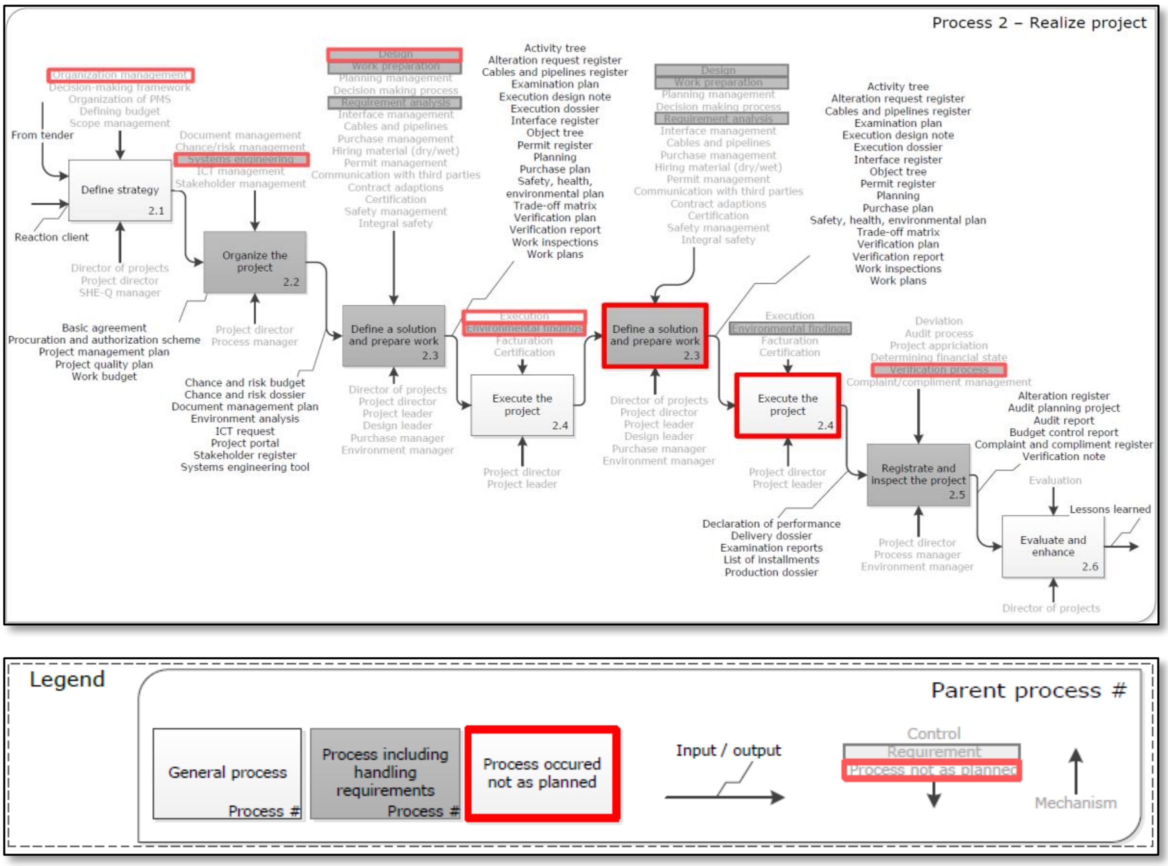


Figure 25 – Visualization of the realization process of case 4 (own ill.)

The image above shows the more detailed processes of the realization phase. Deviations from the standard process again are delineated in red. It appears that the execution process resulted in problems after which the design process was conducted again. When the design was finished, the execution could start over. The cause for this course, as already described in this paragraph, lies in the fact that the design was based on a situation on site which proved to be different during the execution. An important note is that the execution of the project did not stop right after the problems in the execution emerged. Some of the problems were solved right away without consulting the client or the contract. Therefore the design deviated from the contract even more, resulting in a step back to the design phase in order to fix it.

Next to the course of the process, some of the controls have been executed different than planned. Organization management has proven to be difficult in this project resulting in a high rate of change in the project team. Systems engineering had little support and errors in the initial design resulted in problems in the execution due to environmental findings. Finally, the verification process caused problems since not all quality could be proven or assured.

5.4.2 *Failure costs from literature*

The visualization which can be seen in Figure 26 indicates which potential causes for failure costs from literature have occurred in the project.

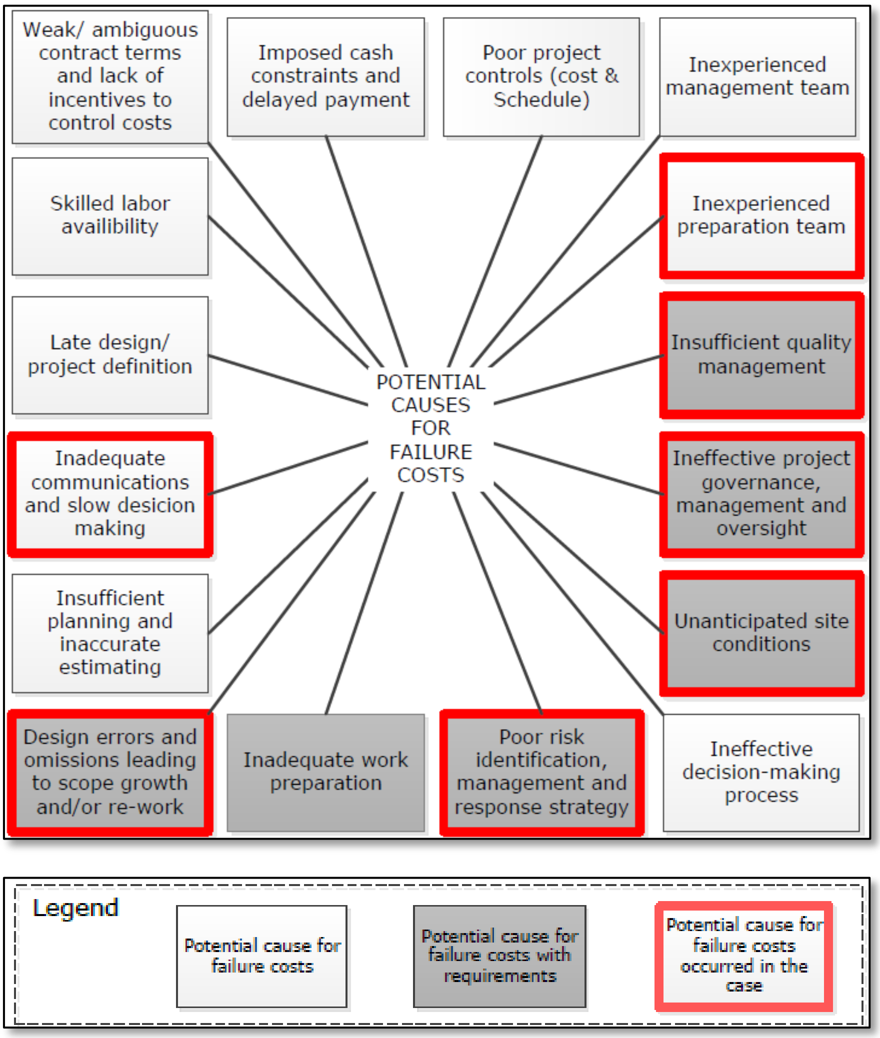


Figure 26 – Visualization of the potential causes for failure costs of case 4 (own ill.)

The image above shows the potential causes for failure costs from literature which are delineated in red when these causes were present at the fourth case. The team was inexperienced and communication with the client was inadequate. Ineffective systems engineering was applied and unanticipated site conditions and design errors occurred, which have a direct relationship. Risk identification, management and response strategy could have prevented the problems resulting from the differing site conditions. The fact that verification has proven to be difficult in delivery of the project results in the delineated box insufficient quality management.

5.4.3 *Concluding*

Concluding, the process has had major problems in the realization, as a result of which, the design had to be made again. Furthermore, there were problems in the organization control of the project and systems engineering and verification have proven to be difficult. There were a lot of controls which have not occurred as intended by the standard process.

As the case description indicates, a major problem occurred during the execution phase as a result of which, the design had to be reconsidered. Hence, the problem definition is confirmed for this case.

5.5 Case 5

The last case consists of a large infrastructural work in which roads and civil structures were built. The client delivered a reference design and a set of requirements which was input for a more detailed design by the contractor at the end of the tender phase. After the project was awarded, the design was elaborated further and construction started. Conditions at the site proved different during execution after which the design had to be altered. Furthermore, discussion arose about the interpretation of several requirements by the contractor.

The project had disappointing results in both time and budget.

5.5.1 Process

For this case, there is no deviation from the general process as described by the standard process, nor is there a difference in the occurrence of the controls. Therefore the tender phase is described directly in Figure 27. The realization process can be seen in Figure 28.

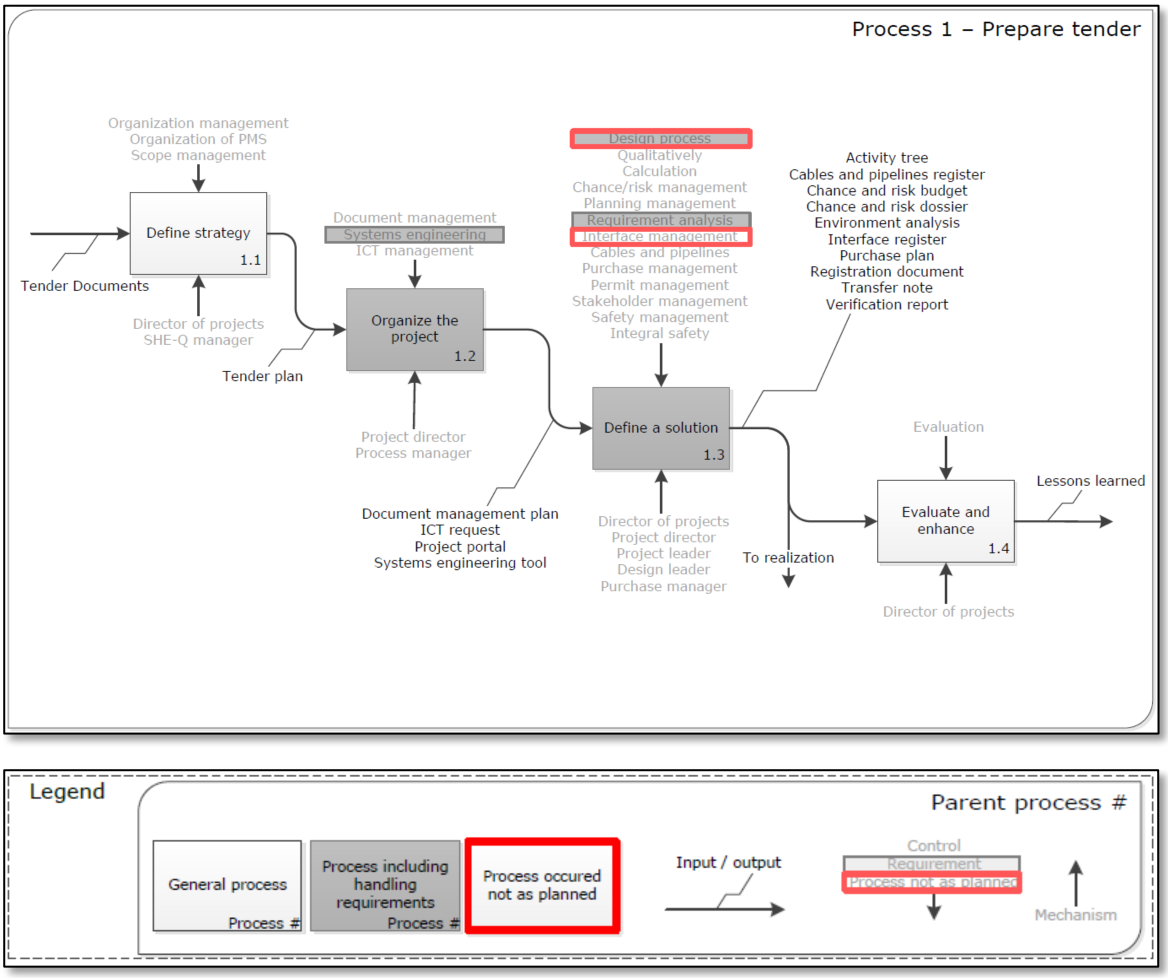


Figure 27 – Visualization of the tender process of case 5 (own ill.)

The image above shows the more detailed processes of the tender phase, in which we can distinguish deviations from the standard process delineated in red. It shows that the design process and interface management have proven to be problematic controls in the tender. The design was made based on a reference design by the client and was based on assumptions about a situation at the site which eventually proved to be different. Interface management was not applied in the tender.

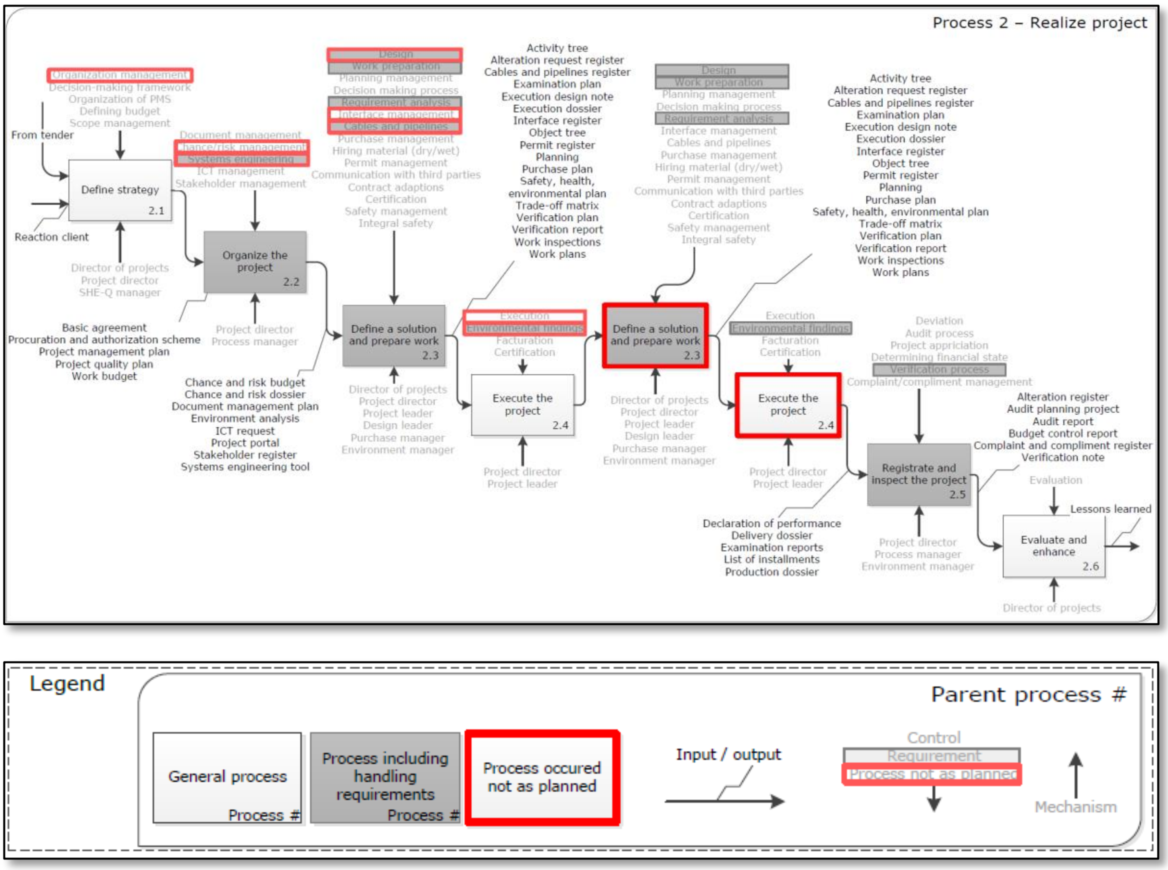


Figure 28 – Visualization of the realization process of case 5 (own ill.)

The image above shows the more detailed processes of the realization phase. Deviations from the standard process again are delineated in red. The execution process resulted in problems after which the design process was conducted again. When the design was finished, the execution could start over. The cause for this course, as already described in this paragraph, lies in the fact that the design was based on a situation on site which proved to be different during the execution. An important note is that the execution of the project did not stop right after the problems in the execution emerged. Some of the problems were solved right away without consulting the client or the contract. Therefore the design deviated from the contract even more, resulting in a step back to the design phase in order to fix it.

Next to the course of the process, some of the controls have been executed different than planned. Organization management was difficult, the project team initially was understaffed and changed significantly over time. The application of chance and risk management and systems engineering was insufficiently applied in the project. Interface management was underexposed and problems with cables and pipelines have delayed the progress.

5.5.2 *Failure costs from literature*

The visualization which can be seen in Figure 29 indicates which potential causes for failure costs from literature have occurred in the project.

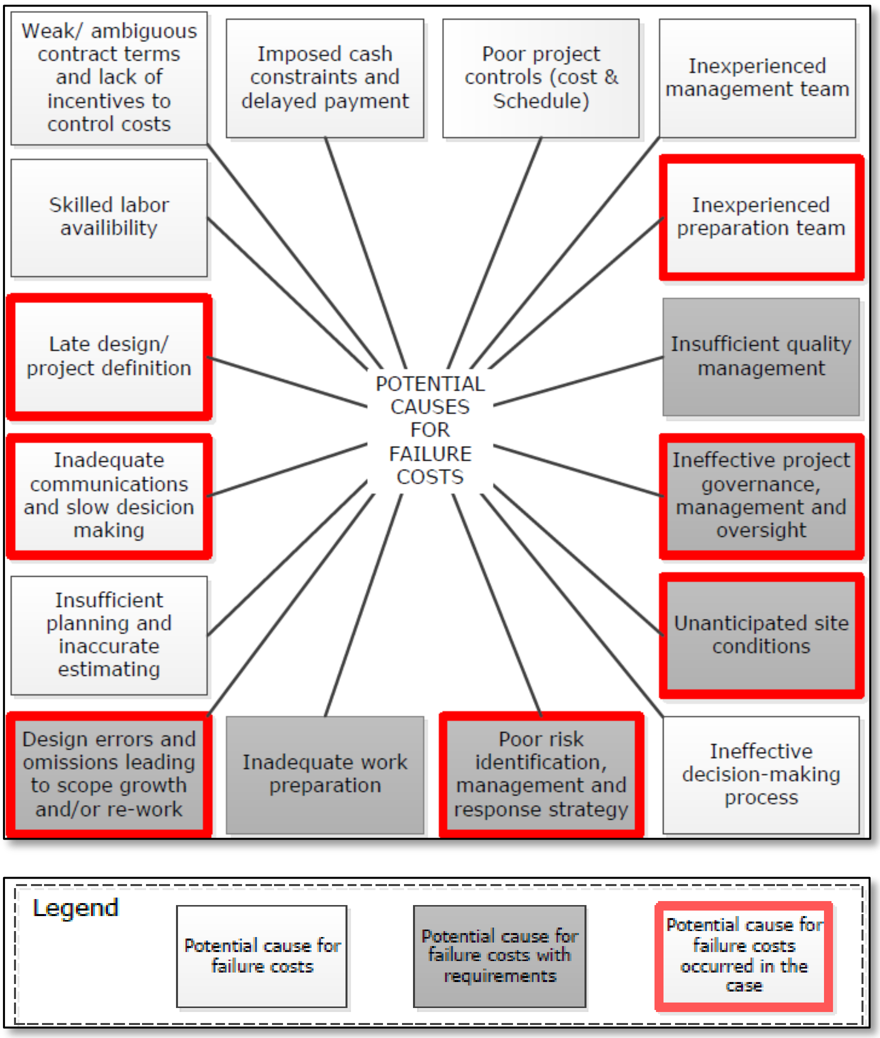


Figure 29 – Visualization of the potential causes for failure costs of case 5 (own ill.)

The image above shows the potential causes for failure costs from literature. Delineated in red are the potential causes for failure costs which occurred at the fifth case. We can see that the team was inexperienced with the contract type and that the design was late. The communication with the client can be stated as inadequate since decisions were not discussed. Furthermore, problems in systems engineering (ineffective project governance, management and oversight) occurred. Unanticipated site conditions and design errors have a direct relationship. Risk identification, management and response strategy could have prevented the problems resulting from the differing site conditions.

5.5.3 Concluding

Concluding the project has coped with large problems in execution which resulted in adaptions of the design. The project organization was problematic leading to large reorganizations. A late design and delays as a result of cables and pipelines had an important impact on the schedule.

Some of the problems occurring at this project were the result of processes which handle requirements. As the case description indicates, a major problem occurred during the execution phase as a result of which, the design had to be reconsidered. Hence, the problem definition is confirmed for this case.

5.6 The results of the approaches

This paragraph sums up the results from the both case approaches in order to be able to designate the problematic processes and potential causes for failure costs. At first, the process approach will be elaborated, starting with the general course of the project and ending with the controls of the project. After that, the potential causes for failure costs will be elaborated.

An important aspect of the analysis of the cases is that all cases have had problems with processes in which requirements are handled and therefore the problem definition is confirmed in all cases. Another major remark is that the projects all have different extents to which failure costs have occurred. The most problematic cases have been case 4 and case 5, case 1 and case 2 have had some problems and case 3 had only minor setbacks.

5.6.1 The process based approach

When considering the general construction process (process 0) for all projects, case 1 and case 2 differ from the original course. Case 1 has a repetitive character in which the realization is repeated four times. The reason for this alteration is the maintenance character of the project. Every year a new area is selected for maintenance which is regarded as new input for the realization process. As a result of this, all controls within the process have to occur again. In case 2, a step back was taken from the realization to the tender. After the project was awarded, the client had to alter the request for the project which resulted in the need for a new tender design. The cases 3, 4, and 5 show no difference between the actual course and the standard progress. So there are no major alterations from the standard process which are attributable to flaws by the contractor.

When the processes in the tender and realization phase are considered, it can be concluded that there are no major alterations between the standard process and the course of the process in the tender phase. However, when realization process is regarded, the course of the process alters in case 4 and case 5. The need for revising the proposed solution once the execution phase had started can be distinguished. The course of the other cases has occurred as planned.

Since the courses of the processes have been considered, the controls of the processes can be regarded. A summation of all the problems with controls can be seen in Table 3 and Table 4. Per control, the nature of the problem is indicated in order to comprehend the influence of the problem.

Tender	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Systems engineering	Not applied	Not applied	Not applied	Not applied	
Design	Not applied	Not applied	Not applied	Insufficient	Not applied
Chance/risk management		Not applied		Insufficient	Not applied
Interface management	Not applied	Not applied			

Table 3 – The alterations from the standard tender process per case

The table above shows the alteration within the controls for the processes in the tender phase from the standard controls. It is interesting to see that even though the biggest problems occurred in other cases, the most deviations from the tender controls occurred in case 2. The fact that a process is not completed as planned can therefore merely be seen as an indication for potential problems.

Realization	Case 1	Case 2	Case 3	Case 4	Case 5
Organization management				Problems/ insufficient	Problems/ insufficient
Systems engineering		Little support	Little support	Little support	Little support
Design		Problems		Problems	Problems
Chance/risk management				Insufficient	Insufficient
Interface management					Problems
Cables and pipelines			Problems		Problems
Verification process	Problems	Problems	Problems	Problems	
Execution				Problems	Problems
Environmental findings		Problems		Problems	Problems

Table 4 – The alterations from the standard realization process per case.

The table above shows the alteration within the controls for the processes in the realization phase from the standard controls. It is interesting to observe that problems in organization management, chance and risk management, and execution only occur at case 4 and 5. Furthermore, apparently, little support of systems engineering is not per definition a cause for problems, but proper systems engineering in the tender might be correlated to a trouble free verification process.

Errors in the design and environmental findings also occur in both case 4 and 5, but also in case 2.

5.6.2 *The failure cost based approach*

This paragraph will provide a summation of the potential causes for failure costs which occurred in the cases. An overview can be found in the following table.

Failure costs	Case 1	Case 2	Case 3	Case 4	Case 5
Inexperienced team		Yes	Yes	Yes	Yes
Ineffective project governance, management and oversight	Yes	Yes	Yes	Yes	Yes
Unanticipated site conditions		Yes		Yes	Yes
Poor risk identification		Yes		Yes	Yes
Design errors and omissions leading to scope growth and/or re-work	Yes	Yes		Yes	Yes
Inadequate communications and slow decision making				Yes	Yes
Late design/ poor project definition		Yes			Yes
Insufficient quality management	Yes	Yes	Yes	Yes	

Table 5 – The occurrence of potential causes for failure costs per case

The table above shows the events which have occurred in the different cases which have potentially led to failure costs, according to literature. Since we know case 4, and case 5 were the most problematic from financial perspective, it is interesting to see that inadequate communications and slow decision making is an event only occurring in those cases. Furthermore, apparently ineffective project governance, management and oversight, with which the application of systems engineering is implied, appear to have occurred in all cases.

The inexperience of a team apparently is not directly correlated to problems in the projects. Unanticipated site conditions, poor risk identification and late design are events that took place in case 4 and 5, but also in case 2. Design errors have occurred in all cases but case 3, which has the best results.

5.6.3 *The comparison*

We have now considered all major problems which have occurred in the cases, but since there are no weighting factors taken into account when considering these problems, all aspects have to be part of a following analysis. Since the course of the processes is the result of the controls and the mechanism, a combination of the controls and the human influence will be taken into account in determining the problematic proceedings with requirements. This will be elaborated in the following chapters.

In the analysis, which is described in chapter 7 and 8, the problems highlighted in this paragraph are compared to the results of the interviews after which the potential causes behind the problems can be revealed. In order to do so, it is important to consider all the problematic events. Some of the results from the process based approach and the failure cost based approach have the origin in the same problematic process. Since the goal of this analysis is merely to identify the problematic processes, the problematic process based controls can be connected to the events that potentially lead to failure costs. The two entities do not have to be similar and mutually exclusive, but merely have to occur in the same process. The events which will be taken into consideration can be seen in Table 6.

Process based control	**Failure costs based event**
Systems engineering	Ineffective project governance, management and oversight
Design	Unanticipated site conditions
	Design errors and omissions leading to scope growth and/or re-work
	Late design/ poor project definition
Chance/risk management	Poor risk identification
	Ineffective project governance, management and oversight
Interface management	Ineffective project governance, management and oversight
Organization management	Inexperienced team
	Inadequate communications and slow decision making
	Ineffective project governance, management and oversight
Cables and pipelines	
Verification process	Insufficient quality management
Execution	
Environmental findings	Unanticipated site conditions

Table 6 – The correspondence between the process based approach and the failure cost based approach

The table above shows that multiple potential problematic events as a result of the process based approach and the failure cost based approach. The events can be compared to each other and correspondence can be designated. The correspondence does not have to be finite, since the goal is merely to identify problematic processes.

The problems in the control systems engineering can be regarded as ineffective project governance, management and oversight. Problems in the design can be coupled to unanticipated site conditions, design errors and omissions leading to scope growth and/or re-work, and late design/ poor project definition. Chance and risk management is considered to correspond with Poor risk identification and ineffective project governance, management and oversight. Organization management is correlated with an inexperienced team, inadequate communications and slow decision making and ineffective project governance, management and oversight. Problems in the verification process align with insufficient quality management. Finally, the unanticipated site conditions, which are also connected to the design, correspond with the environmental findings control.

To observe the impact of the different controls, a model consisting of the controls from Table 6 will be described in the next chapter. Since the hypothesis is not yet rejected based on this part of the research, design and risk have to be part of the model.

6. Proceedings with requirements and perception

Since the problematic processes and controls are now known, this chapter will consider the tools for identifying the proceedings with requirements and therefore the human factor in these processes and controls. For doing so, potential models for visualizing the processes will be considered after which the impact of interpretation is integrated by the elaboration of certainty, uncertainty and risk.

The scope of the research, as has be seen in Figure 1, changes in this chapter from the entire process to problematic processes with requirements. Therefore, this chapter will elaborate a model which describes these processes with requirements.

The result of this chapter will be a model describing the problematic processes in combination with the human influence within these processes. Finally an approximation of the extent of the human influence will be elaborated.

6.1 Potential models

Since the purpose of the model is analysis of proceedings with requirements, the model should be focused on processes with requirements. Furthermore, the human influence should be part of the model, or there should be a possibility of adding it. As stated before; systems engineering is a problem solving approach in which requirements are translated into system elements (US Department of Defense, 2001), making a systems engineering approach suitable for this research.

According to Sage & Armstrong, there are several potential systems engineering models for describing a process with requirements, namely:

1. The V-model
2. The V-model with prototyping
3. The evolutionary process model
4. Incremental development

(Sage & Armstrong, 2000, pp. 78-81)

Wasson adds the following models for describing a process:

5. The Waterfall Development Model
6. The Spiral Development Model

(Wasson, 2006, p. 290)

The V-model actually is a waterfall model with the benefit of the view on the life cycle from the perspectives of user, systems architect, and programmer. The V-model with prototyping considers the V-model with prototype development and testing for every step of detail in the process. The major purpose of evolutionary development is to allow for the recognition of the fact that user requirements cannot be initially obtained. Incremental development can be stated as the buildup of a system element per element (Sage & Armstrong, 2000). The spiral development model focusses on a spiraling increase of maturity of a system by prototyping taking risk into consideration.

Since there is no need for prototyping, option 2 is discarded. The fact that requirements are the starting point of the project makes that option 3 can be discarded as well. Finally, the spiral development model focusses merely on the design, making it less attributable for the research. The waterfall model is adapted in the V-model, leaving the incremental development model and the V-model as potential models for the research.

The major advantage of the V-model over the incremental development model is that the V-model describes the parallel processes which occur in a project, where the incremental development model merely describes the sequential buildup of a design. Evidently, the V-model will be considered for the description of proceedings with requirements. The hypothesis is not rejected, so the design should be part of the mode, which is the case at the V-model. The theory behind the V-model will be explained based on Wasson, INCOSE, the US Department of Defense and Sage & Armstrong, as had been elaborated in chapter 3.

6.2 The v-model

This paragraph will describe the different views on the V-model. For this comparison, Wasson, INCOSE and the US department of defense will be considered. The chapter will conclude with a description of the view which will be used for this research after which the connection with human influence is made.

6.2.1 Wasson

According to Wasson, the V-Model is "a graphical model that illustrates the time-based, multi-level strategy for (1) decomposing specification requirements, (2) procuring and developing physical components, and (3) integrating, testing, evaluating, and verifying each set of integrated components" (Wasson, 2006, p. 266). The V-model according to Wasson can be seen in Figure 30.

When considering the V-model as described by Wasson, "the progression has numerous feedback loops to perform corrective actions for design flaws, errors, and deficiencies." (Wasson, 2006, p. 272). Time proceeds from left to right towards acceptance of the system, while iterations happen in a vertical motion. Iteration means re-working some of the specifications, designs, or components which have been worked on earlier (Wasson, 2006, p. 272).

Next to the feedback loops, the V-model also "illustrates where and how system development programs become "bottlenecked," consuming resources without making earned value work progress because of re-work (Wasson, 2006, p. 272). Early adaption of systems engineering can play a major role in avoiding these bottlenecks by minimizing or even mitigating the risk of re-work (Wasson, 2006, pp. 272-273).

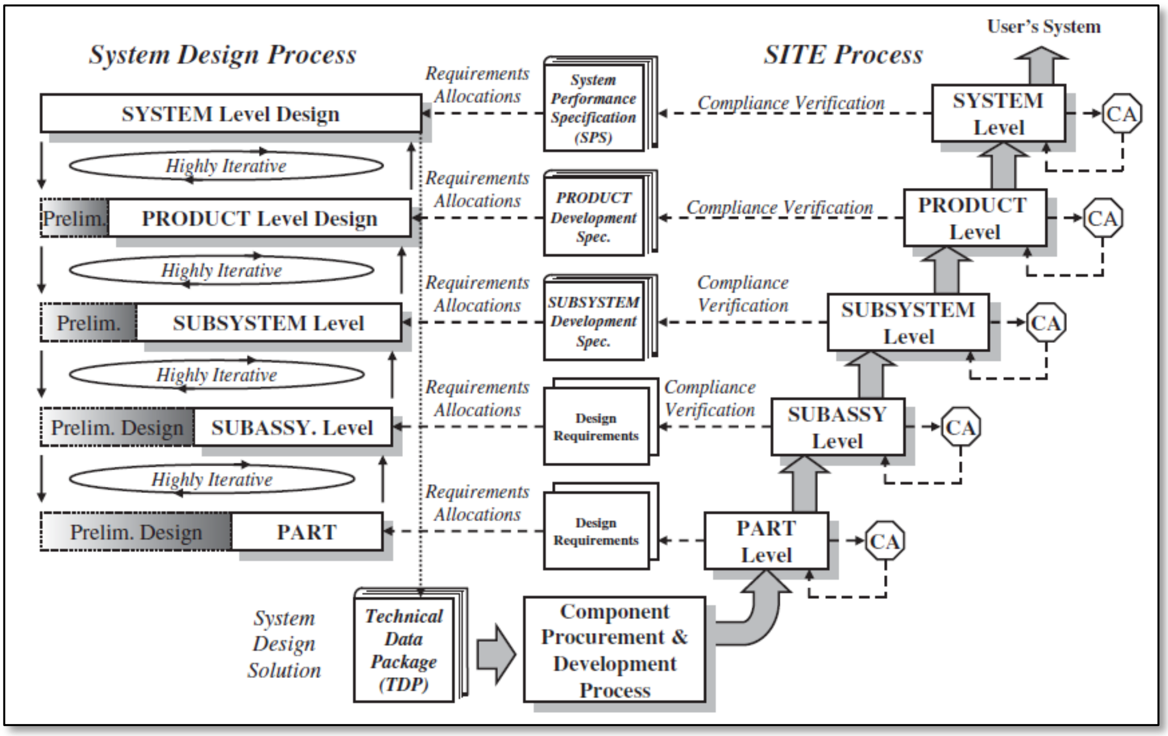


Figure 30 – The V-model according to Wasson (Wasson, 2006, p. 272)

The model starts on the left with a design on system level, slowly developing it further over time towards a technical data package in which all design choices are incorporated. Between all levels of the design and between the design and the original requirements, iteration takes place in order to learn from previous decisions. Once the design is completed, the technical data package is translated into documents for execution. Every level of execution on its place verifies the requirements and every subsection that is completed contributes to the integration of the requirements. The result of the process is a system for the user which applies to all requirements (Wasson, 2006).

6.2.2 *INCOSE*

INCOSE defines the V-model as follows: "The Vee model is used to visualize the system engineering focus, particularly during the concept and development stages. The Vee highlights the need to define verification plans during requirements development, the need for continuous validation with the stakeholders, and the importance of continuous risk and opportunity assessment" (INCOSE, 2006, p. 3.4). INCOSE furthermore divides the V-model into two different parts, the left side of which can be seen in Figure 31 and the right side of which can be seen in Figure 32.

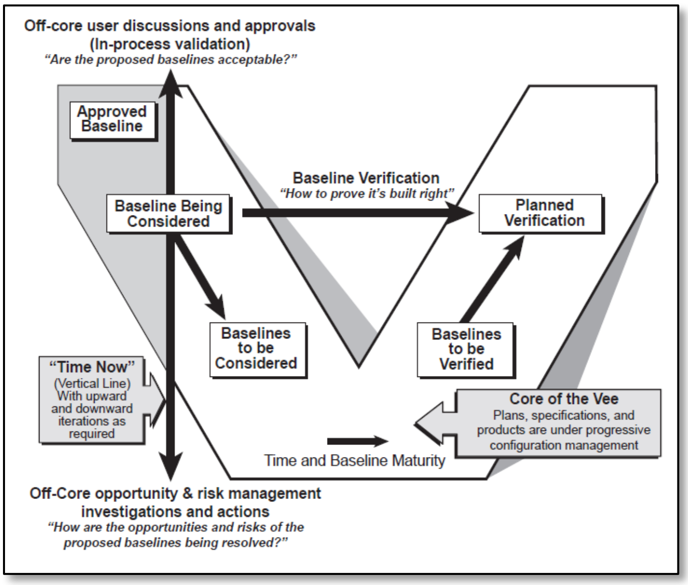


Figure 31 – The left side of the V-model according to INCOSE (INCOSE, 2006, p. 3.6)

The left side of the V-model, as visualized above, describes the place in time on the horizontal axis. The left side of the V-model describes the iterations in the design phase in order to ensure that the design is feasible. It focusses on a vertical approved baseline which moves to the right over time. The model considers the decomposition phase consisting of pre-concept exploratory research, concepts, and development. It covers the approval of the design.

As the approved line exceeds to the right, the content to the left of the line is approved by verification of the design. Simultaneously, the methods for proving that the approved part of the design has been properly executed in the right leg of the V is elaborated.

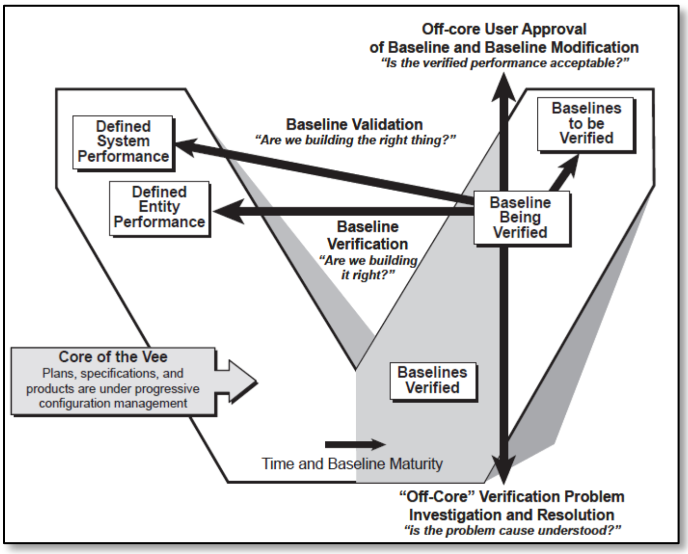


Figure 32 – The right side of the V-model according to INCOSE (INCOSE, 2006, p. 3.8)

The right side of the V-model, as can be seen above, describes the iterations in the execution phase in order to ensure that the production stage is feasible. It considers the integration phase and therefore the production. It covers the verification of the design.

6.2.3 US Department of Defense

According to the US department of defense "The Systems Engineering Process (SEP) is a comprehensive, iterative and recursive problem solving process, applied sequentially top-down by integrated teams. It transforms needs and requirements into a set of system product and process descriptions, generates information for decision makers, and provides input for the next level of development. The process is applied sequentially, one level at a time, adding additional detail and definition with each level of development. The process includes: inputs and outputs; requirements analysis; functional analysis and allocation; requirements loop; synthesis; design loop; verification; and system analysis and control." (US Department of Defense, 2001, p. 31). Figure 33 shows the decomposition of requirements into a design and therefore the left side of the V-model. The high rate of iteration and the role of verification is made clear between the several steps of the process; requirements analysis, functional analysis and allocation, and synthesis.

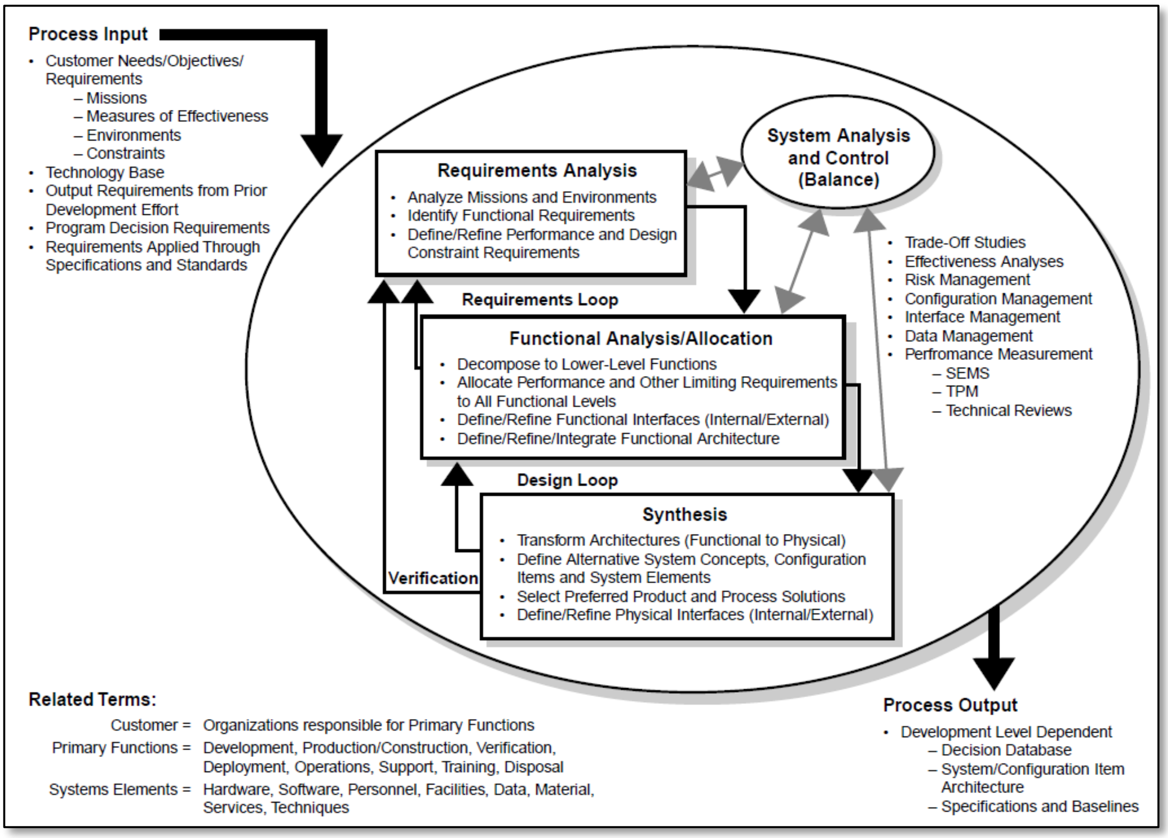


Figure 33 – The systems engineering process (US Department of Defense, 2001, p. 31)

The image above shows that the process starts with input which is defined as customer needs, technology, output from prior processes, internal requirements and requirements from regulations. The input enters the systems engineering process in which the requirements are first analyzed based on their characteristics. After that, the input is subject to a functional analysis and allocation of the requirements in which the requirements are further decomposed and allocated and the functional architecture is defined. Notice that there is a requirement loop back to the requirements analysis in order to ensure iteration. After the functional analysis and allocation, synthesis of the input ensured the transformation of the requirements to system elements to prepare them for realization. The output of the systems engineering process is a system element of which the level of development is dependent on the level of development of the systems engineering process.

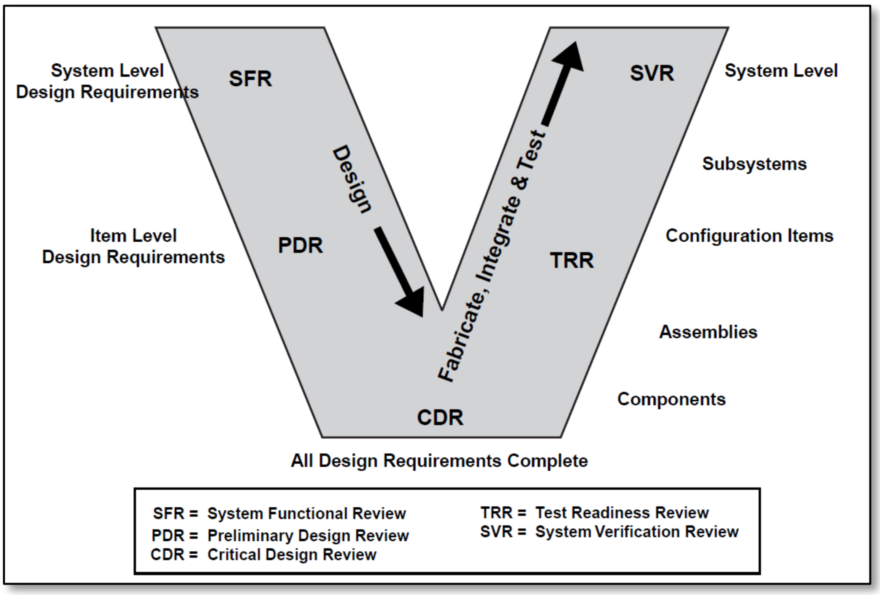


Figure 34 – Systems engineering and verification (US Department of Defense, 2001, p. 65)

The image above shows the V-model according to the US department of defense. The left leg of the V-model consists of the design process. The right side of the model entails fabrication and integration. The levels of development are shown on the right of the model. These levels of development consider the design phase and the integration phase. The left side of the model is subject to the systems engineering process, the right side is not.

When the left side of the V-model is considered as decomposition, the right side of the V-model can be defined as integration and execution, as can be seen in Figure 34. The US Department of Defense also states that design is a top-down process while the Verification activity is a bottom-up process (US Department of Defense, 2001, p. 66), encompassing the former statements. The integration of the project is divided into several levels of detail.

6.2.4 *Comparison and own definition*

The models and definitions share the view that the V-model is a tool for visualizing an integrated systems engineering strategy for mitigating re-work risk and ensuring a smooth process. They however differ in approach when it comes to the process it assesses. INCOSE focusses on verification plans, stakeholder validation and risk and opportunity assessment and therefore defines important proceedings without assigning certain phases of the project. Wasson focusses on the decomposition of requirements, component development and proper integration of the components, which is more phase specific (design, realization). The US Department of Defense uses the model to describe a highly iterative process with specific proceedings per step in the process. The focus is on the design and therefore the left side of the V-model. A combination of these models should lead to a V-model and definition which assesses the most important steps and assigns them to a phase. A visualization of this model can be seen in Figure 35.

The process entails the decomposition of the input and a translation to a final design. When this final design is finished, execution can start re-integrating the requirements by construction of the works.

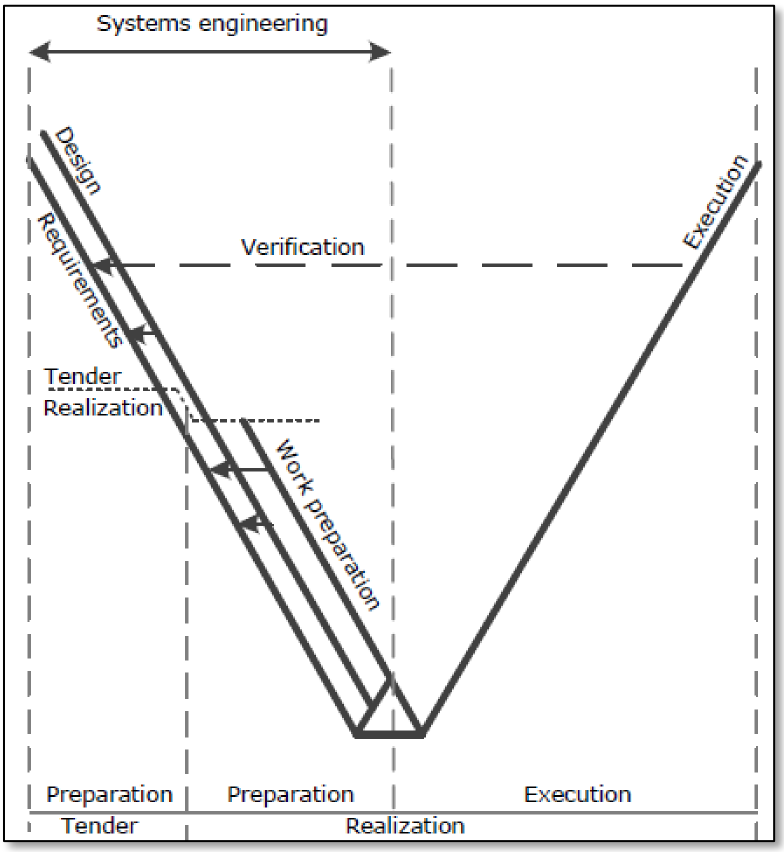


Figure 35 – The V-model (own ill.)

The image above shows the V-model as used for this report. As the V-models described earlier, the left side of the model describes the decomposition of requirements and the right side of the model describes the integration of the requirements. The model however differs on some crucial elements from the ones described before. At first, systems engineering is indicated to occur merely in the decomposition phase. This is because systems engineering is a problem solving approach in which requirements are translated into system elements, as described by the US department of defense.

Furthermore, a distinction between the tender and the realization phase is included in the decomposition. The stepped line indicates that the decomposition of requirements and the inclusion of these requirements in the design are independent parallel processes. Furthermore it indicates that the decomposition of requirements is incomplete from the moment the tender phase is ended, which is of major importance for the following steps. The position of the line separating the tender from the realization differs per project. Furthermore, the left side of the V-model is divided into requirement decomposition, design and work preparation which is added in the decomposition phase after the tender.

When the tender is awarded and the final design has to be made, the decomposition continues to a point at which the execution can start. During the execution, iteration still takes place towards the design, but also towards the requirements in the form of verification.

The decomposition of requirements is a parallel process to the development of the design; the one process needs the other in order to satisfy the client's demands. Iteration in this image is a process which occurs from right to left, time proceeds from left to right, decomposition from top to bottom and integration from bottom to top.

The distinction between the tender and the realization phase indicates that the tender phase is ended when there is enough trust in the control of time (planning), quality (design) and costs (calculation), making the process subject to perception. This trust has to be estimated by the direction by considering the risk for overruns of time or budget based on calculations or experience. Therefore, the following chapter will describe the influence of this perception on information and therefore the V-model.

6.3 Adding interpretation via the certainty model

This paragraph first describes the influence of the human factor and interpretation on information and will eventually combine a model which describes interpretation with the V-model. The influence of the human factor has to describe risk since the hypothesis is not yet rejected the design aspect is already part of the V-model. The human influence is elaborated by considering expectation versus what will happen by De Ridder (De Ridder, 2013), known and quantifiable costs by Molenaar (Molenaar, 2005), and epistemic and aleatory certainty by Matsumura and Haftka (Matsumura & Haftka, 2013). By doing so, an overview of risk and risk management in construction and the associated design process can be provided while considering approaches from multiple viewpoints differing from professors to project management associations.

6.3.1 Expectation versus what will happen

According to De Ridder, information can have three entities, namely certainty, uncertainty and risk. Certainty indicates that it is exactly known what to expect and what will happen. Uncertainty implies that there is absence of information about what will happen and of what is expected. Risk indicates available information about what can be expected, but not what will happen (De Ridder, 2013, p. 32). This is visualized in Table 7.

	Certainty	Risk	Uncertainty
Known what to expect	Yes	Yes	No
Known what will happen	Yes	No	No

Table 7 – Different entities of information have different properties. To (De Ridder, 2013)

The table above shows the three possible entities of certainty compared with the detail of the knowhow of the event according to De Ridder (De Ridder, 2013, p. 32). If it is known what to expect, there is some knowhow about the event, but the effect of the event is unclear. If it is known what will happen, then the effect is clear.

Since there is merely scarce information in the beginning of a project about what to expect or what will happen, uncertainty prevails. Uncertainty makes place for certainty or risk when research is executed, or in other words, when decomposition of requirements results in implementation into a design. When the design is finished, merely risk and certainty remain. (De Ridder, 2013)

Next to the properties of information, De Ridder also combines the influence of perception on information. Information can interpreted as what is believed to be true without analysis (perceived desired), what is thought to be true based on analysis (perceived actual) and what reality actually is (actual). When the information is perceived to be actual, but has not been analyzed or correctly interpreted, the contractor could be working on useless or extra work, as can be seen in Figure 36.

So according to De Ridder, the certainty of information is based on the equation about what is expected and what will happen. Whether information about what to expect and what will happen is justly assumed to be known is based on the perception of the information by the enabler.

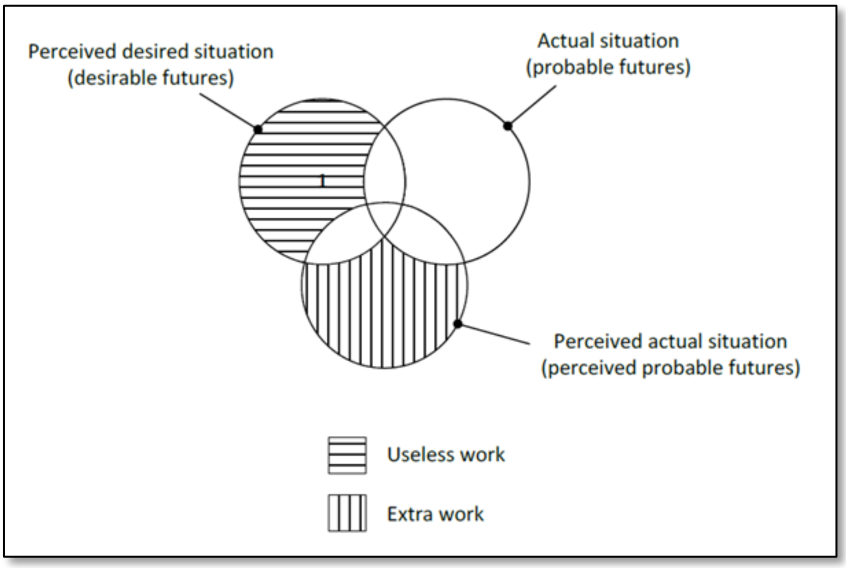


Figure 36 – Work as consequence for perception problems (De Ridder, 2013, p. 41)

The Venn diagram, shown in this figure elaborates the three areas of perception, the perceived desired information, the actual situation and the perceived actual situation. The goal of interpretation is to regard the actual information. There is however a chance that the perceived information, whether it is perceived desired or perceived actual, is not in line with the actual situation. When this is the case, useless or extra work is done, as can be seen in the highlighted areas.

6.3.2 *Known and quantifiable costs*

According to Molenaar information about costs can be either be known or quantifiable (Molenaar, 2005). Information can therefore take three different forms, as can be seen in Table 8.

	Known knowns	Known unknowns	Unknown unknowns
Known costs	Yes	Yes	No
Quantifiable costs	Yes	No	No

Table 8 – Different entities of information have different properties. To (Molenaar, 2005)

This table shows the three possible entities of certainty compared to what is known or what is quantifiable. Quantifiable costs are costs of which the occurrence is certain, known costs are costs of which it is certain that they will occur, but not to which extent. Even though the subject of the certainty is different from the subject of certainty from De Ridder, there is a strong similarity between the approaches.

As can be seen in Figure 37, Molenaar states that costs which are not known or not quantifiable at the start of the project, are partly replaced with known and quantifiable costs as the project proceeds. Costs which have not been recognized diminish as the project matures, but are not completely mitigated until known in the end of the project. Contingency costs are described as the difference between the known costs and the estimates.

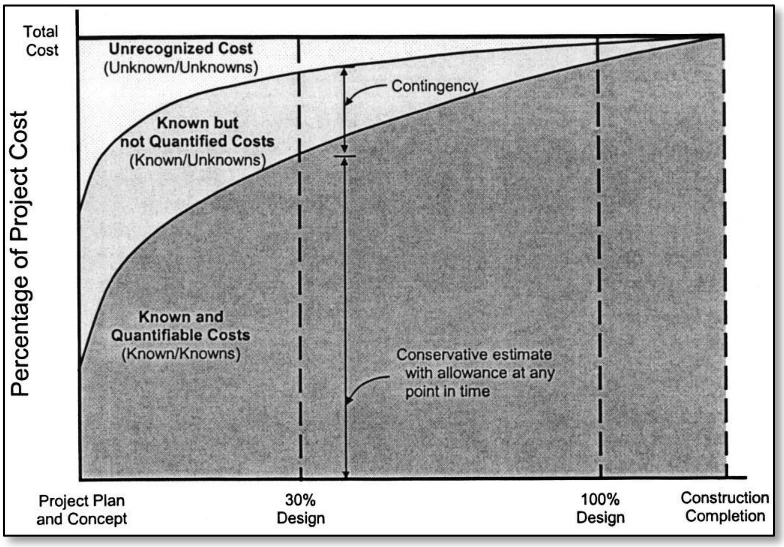


Figure 37 – Conceptual components of a cost estimate (Molenaar, 2005, p. 344)

This figure shows the percentage distribution of project costs over the course of the project, from requirement specification to completion. The horizontal axis describes the extent to which the design is matured, the vertical axis describes the distribution of the project costs. It can be seen that contingency costs are costs which could have been known, but are not quantified. These costs should be taken into account in risk management.

6.3.3 *Epistemic and aleatory uncertainty*

According to Matsumura and Haftka, information can be certain or uncertain and uncertain information can be epistemic or aleatory. Risk is a derivative of uncertain information. (Matsumura & Haftka, 2013)

Aleatory uncertainty comes from information which cannot be certain and is the result of naturally occurring events. Aleatory information can be incorporated in a planning or budget by administering margins on time, cost or quality. In other words, aleatory information can be incorporated by the application of risk. The system response of aleatory information is natural and the probability distribution can therefore be described as can be seen in Figure 38. (Matsumura & Haftka, 2013)

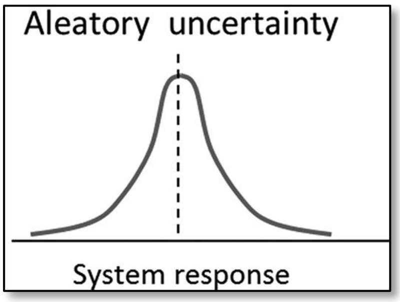


Figure 38 – Aleatory uncertainty (Matsumura & Haftka, 2013)

The image above shows the probability distribution of aleatory uncertainty. The shape tells us that the chance that the event will occur a certain way is the highest at the peak. The further the deviation from the peak, the lower the chance of occurrence. This is a natural, normal distribution. For instance, when a coin is flipped 100 times, the chance that the result will contain 50 times tails and 50 times heads is the most probable. The actual result might however deviate from the probable result.

Epistemic unknown information is information which is based on knowledge and can therefore be refuted by investigation. Epistemic unknown information can be mitigated by research on the matter. Epistemic unknown information results in a bandwidth in which the system will respond, as can be seen in Figure 39.

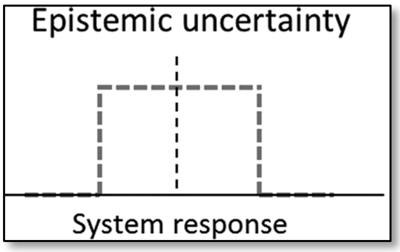


Figure 39 – Epistemic uncertainty (Matsumura & Haftka, 2013)

The image above shows the certainty distribution of epistemic uncertainty. Epistemic uncertainty can be replaced with certainty by means of research. For instance, if the uncertainty concerns the outcome of a difficult mathematical equation, a range in which the answer of the equation will fall can be defined. When the equation is calculated, the range is not needed, since there is a certainty of the outcome.

When epistemic and aleatory system response is combined, the result is a combined uncertainty of which the probability distribution as can be seen in Figure 40. The probability distribution from the aleatory unknown information is expanded by the probability distribution of the epistemic uncertainty.

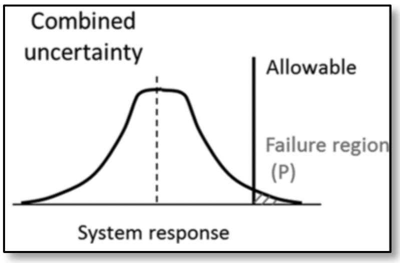


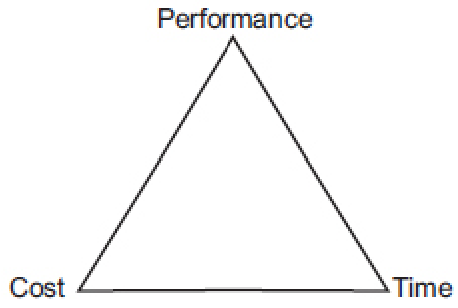
Figure 40 – Combined uncertainty (Matsumura & Haftka, 2013)

This figure shows the combined aleatory and epistemic uncertainty distribution. It shows that uncertainty can be replaced by certainty to a certain extent, after which natural uncertainty remains.

6.3.4 Comparison and own definition

The previous sources describe elements as certainty, uncertainty, risk and the human influence on them. Before a comparison between the multiple theories is made, it is important to understand what the certainty and uncertainty is about for this research. In order do so, the triple constraint method is used. According to the triple constraint method, a project is dependent on time, costs, and performance, as can be seen in Figure 41. Time can be incorporated in a project by means of a schedule, costs by means of a budget and performance by means of a design.

Ideally, certainty is determined over the entire project, taking all aspects of triple constraint into account. However, one of the most important aspects of certainty for this model is that the expected final result of the certainty has to be known at the start of the project. Once the expected value is known, the value that will actually occur can be defined by research and be incorporated as certainty, the remaining uncertainty can be incorporated into the tender as risk, as can be seen in Table 7 and Table 8. The reason for this important distinction is that certainty and risk can be input for the offer in the tender and the realization phase where



uncertainty cannot be determined. In order to be able to decide which of the elements to describe in the model, the characteristics of all entities should be considered.

Figure 41 – triple constraint (Lock, 2007)

The image above shows the triple constraint as used in project management. The quality of a project is dependent on costs, time and performance.

As can be seen in Figure 41, a project is the result of a collaboration between time, costs and performance. An important element in this figure is that the performance has to meet a normative performance. This normative performance is demanded by the client and is stipulated in the contract by means of functional requirements, which define the scope of the research. Furthermore, the time is indicated in the contractor's schedule and will always be defined as a minimum in order to minimize the costs. In other words, the contractor wants to minimize costs and time to deliver the performance demanded by the client.

An approach based on certainty of costs could be a statistical approach based on financial records of projects alike. The approach would be a top down approach in which a forecast could be made based on the expected total costs and probabilistic data. The approach would be based on great amounts of data and therefore be dependent on the statistical analysis of previous project. A normative goal would be calculated based on these data, but cannot be stated as certain. Finally, certainty about costs is determined based on payment strategies and payment terms and therefore be highly submissive to changes in strategy and processes and unforeseen problems.

An approach based on certainty of time could also be a statistical approach based on the course of projects alike, just like the time based approach. The top down methodology would be based on statistical data leading to a probabilistic course of certainty. This approach however has no normative end and is highly submissive to changes in strategy and processes or unforeseen problems.

An approach based on certainty of performance could be a bottom up approach in which the normative performance from the contract can be considered as 100% certainty. The approach would be deterministic and would not be based on previous projects or data. The performance is based on requirements and the normative performance is not influenced by changes in processes and strategy, nor by unforeseen problems.

The normative performance is estimated to be reached within a certain budget and schedule. When unforeseen circumstances arise which negatively influence the performance, time and costs will exceed the initial estimations in order to still meet the normative performance as stipulated in the contract. In other words, these is always an uncertainty in costs and time if the performance is uncertain. However, when only certainty and risk remain in the performance, time and costs can be estimated by means of the incorporation of risk into the budget and schedule, as has been explained in paragraph 6.3.3.

Concluding, only the performance is made normative in the contract by means of requirements which define the scope of this research. Furthermore, certainty and risk from performance can indicate the costs and schedule. Hence, performance will be the subject of certainty for this research. Now a model has to be constructed which considers the certainty in a project over time which can be linked to the V-model. This model is visualized in Figure 42.

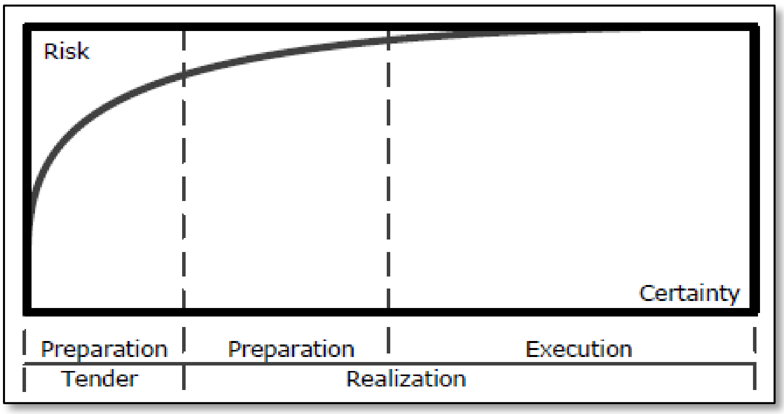


Figure 42 – Risk and certainty model (own ill.)

The model above vertically describes the ratio of distribution between certainty and risk over the horizontal axis of time. When the tender phase is ended, a certain amount of certainty is created in the design, but also, risk remains since the project is not finished yet. The course of the line is indicative and differs per project.

Risk in this model is the difference between the certainty about the performance and the normative performance and is therefore based on aleatory and epistemic uncertainty. Epistemic uncertainty is replaced with certainty as a result of investigation and research. Merely aleatory uncertainty remains after the preparation phase. Research of epistemic uncertainty in this model means further decomposition of the requirements into the design. The remaining uncertainty can be aleatory or epistemic. Remaining epistemic uncertainty is uncertainty for which the result in risk reduction is estimated not to outweigh the consequence.

Figure 42 however does not yet specify the influence of interpretation on certainty and the role of risk and risk management in the tender. When information is perceived to be certain while actually being uncertain, or vice versa, an interpretation bias emerges resulting in a skewed perception of reality. Furthermore, in the tender phase, a product is produced which has to be elaborated in the realization phase, which is therefore incomplete. This means that a certain level of risk remains in the tender phase which is regarded insuperable. When the level of risk is not assessed properly or is no representable rendition of reality due to perception, potentially incorrect decisions are made in risk management. This is visualized in Figure 43.

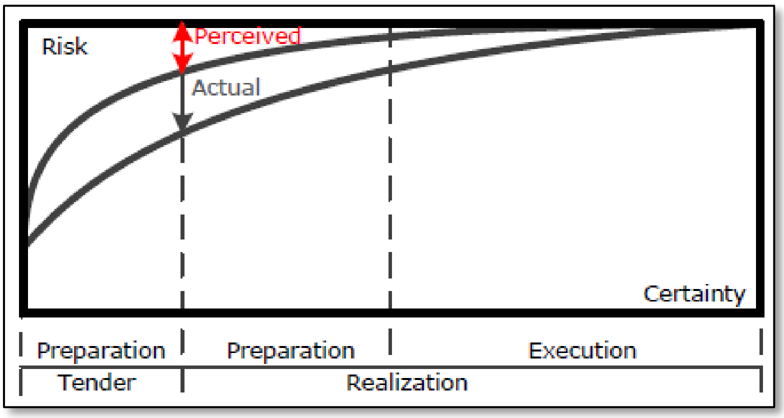


Figure 43 – The result of interpretation on certainty (own ill.)

This figure describes the same model as Figure 42, but it shows the result of interpretation. The continuous curve describes the actual certainty of a project. The dotted curve describes a potential line of perceived certainty. This perceived certainty is the result of assumptions which are taken for granted or other conclusions which are not substantiated or assured. The result of this perception is that the risk which is adopted in the project is reduced to the extent of the red arrow, where the black arrow would be necessary. The risk which is perceived to be certain is not incorporated in the project and is therefore a potential cause for problems.

This model can now be connected to the V-model in order to understand the effect of processes with requirements on the certainty about the performance. The combined models can be seen in Figure 44. This model shows the extent of decomposition of requirements and design and the influence this has on certainty and risk.

The aim of this chapter was to consider the tools for identifying the proceedings with requirements. This is done by considering the human factor in systems engineering, design, chance and risk management, interface management, organization management, cables and pipelines, the verification process, execution, and environmental findings.

The combined model describes systems engineering, design, the verification process, and execution in the V-model. Chance and risk management is considered in the certainty model and interface management as a means of translating the design into work preparation. Cables and pipelines and environmental findings are considered as input for the design and chance and risk management. Organization management determines the controller in the IDEFØ methodology and therefore the human influence.

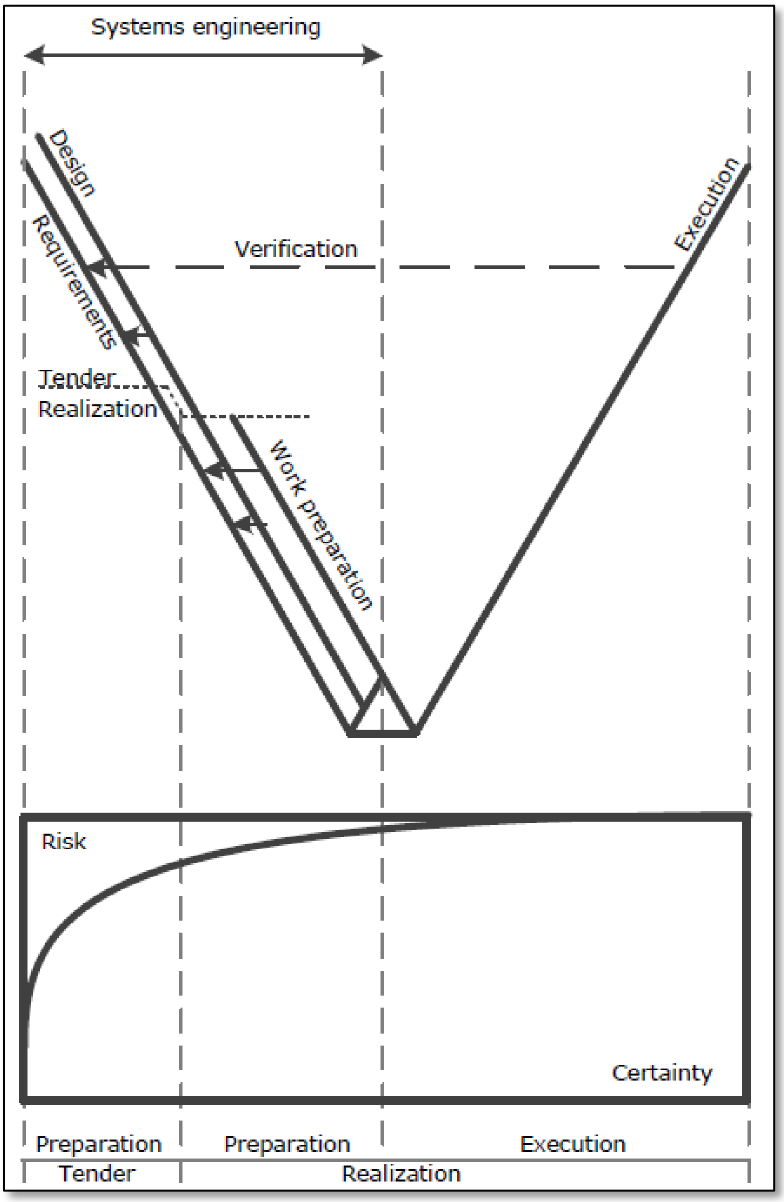


Figure 44 – The V-model including certainty (own ill.)

The image above shows the V-model connected to the certainty model. In this visualization, the V-model is regarded as dominant and the certainty model is a derivative. Time occurs from left to right. In the V-model, iteration occurs from right to left, decomposition from top to bottom and integration from bottom to top.

The preparation phase exists of a tender part and a realization part. This preparation consists of design and requirement decomposition to which work preparation is added after the tender phase. During this preparation, certainty is built up and risk is diminished. In the execution, the last risk is removed until the as built drawings can be made and the project is finished.

6.4 The influence of the level of detail on certainty

An important variable in the combined model is the ratio between certainty and risk. In Figure 43 we have already seen that the influence of perception on certainty can have an important impact on risk management and be a potential cause for problems. Determining the bias of perception can be approximated by means of approximation of the actual certainty and the perceived certainty. The actual certainty about the performance is certainty that emerges from a design of which the correctness has been assured. The difference between actual and perceived certainty occurs when this correctness has not been assured, but is used in the design without the incorporation of risk.

When filing the tender, a little uncertainty remains about the exact content of the project, but the main aspects and the outlines of the project are clear. The level of detail at the end of the tender phase is far from sufficient for construction. The certainty at the end of the tender is defined by determination of the character of the project elements. The preparation phase then determines the methods for realizing that character by increasing the level of detail. A high level of certainty is therefore not the result of a high level of detail of the design, but of the extent in which the outlines of the project are clear.

Certainty is the subjective result of experience and knowledge. When a project has been executed numerous times, the level of detail needed for 95% certainty is lower than when there is no experience with a project alike whatsoever. Based on this experience with the type of project, the level of detail can be determined which is needed for an extent of certainty which is believed to be sufficient for the tender. When errors are made in the achievement of the level of detail, the certainty is perceived to be higher than it actually is. This means that the remaining risk is not integrated in the project and there is a high probability for errors.

The level of detail therefore is low at the end of the tender phase, but increases when the end of the preparation phase approaches. This is visualized in

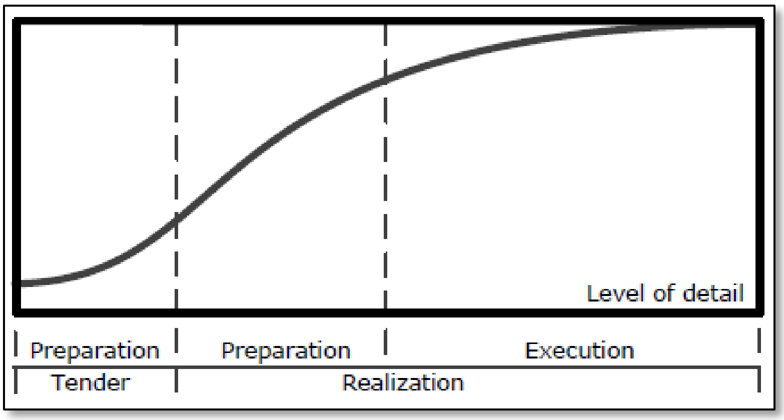


Figure 45 – The level of detail over time (own ill.)

This figure shows the level of detail at the end of the tender, the end of the preparation phase and at the end of the project. The level of detail starts low and increases as the preparation phase approaches.

The goal of the tender is to file a proposal in which time, performance and the budget are certain. Therefore, the goal of the tender is to reach high certainty. The goal of the preparation phase is to prepare the promises from the tender for construction and therefore reaching a certain level of detail. The relation between certainty and the level of detail as a result of the V-model is shown in Figure 46. The figure describes all aspects of the hypotheses, namely the design and risk and is therefore suitable for the research.

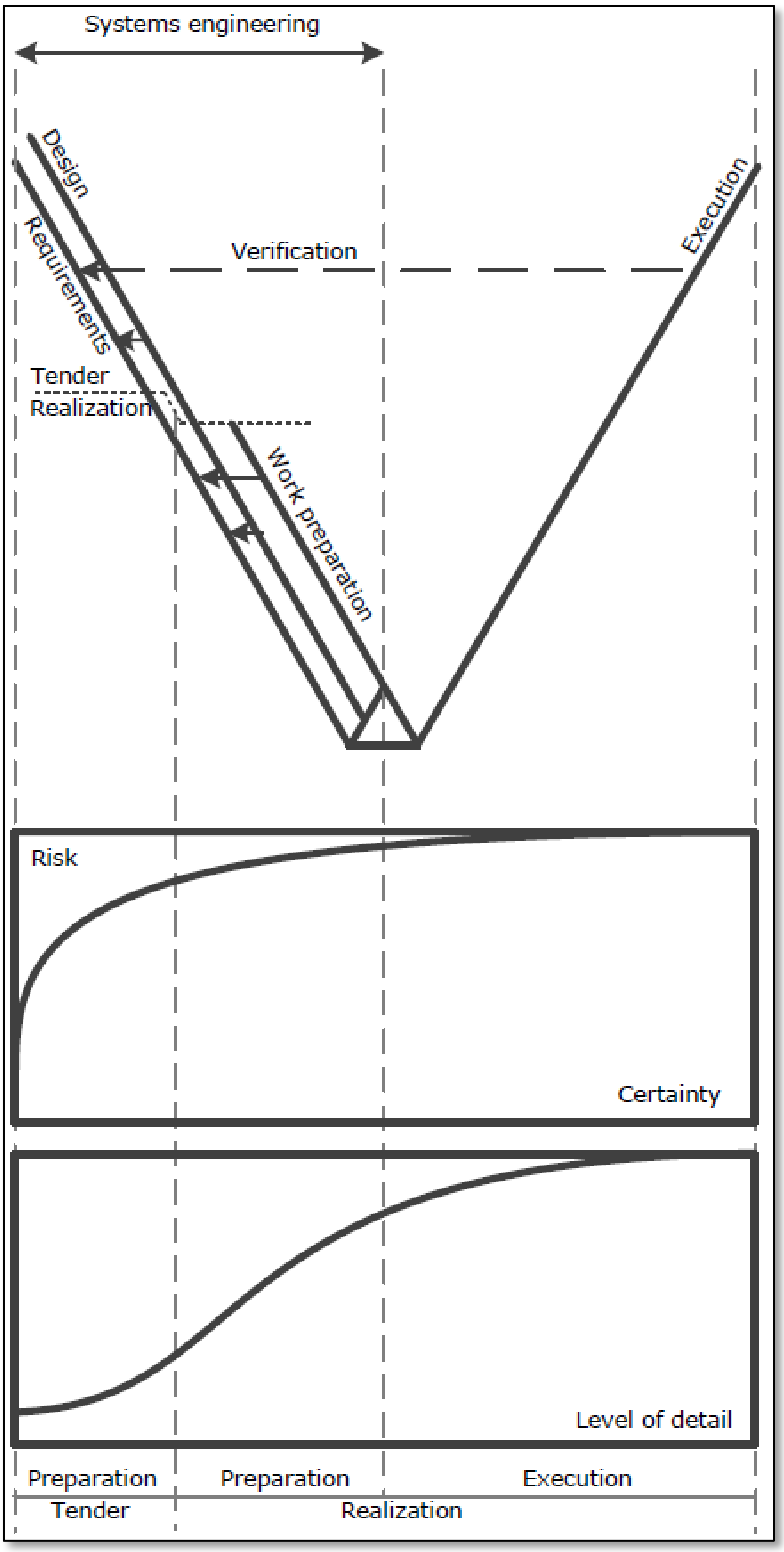


Figure 46 – The level of detail and the certainty influenced by the V-model (own ill.)

High certainty of performance is reached at the end of the tender phase as the result of decomposition of the requirements and the incorporation of them in the design. The level of detail increases significant in the preparation phase of the realization in order to ensure that the promises from the tender phase can be realized in execution.

6.4.1 The different systems

$System_{new}$ can be influenced by the decomposition of requirements into the design for $System_{new}$. The impact of the decomposition and therefore the level of detail of the design can be determined on a methodology which is widely used in construction.

The levels of detail are based on descriptions widely used in design in the construction industry by KIVI. The description describes a design for $System_{new}$ that starts with a set of requirements which are translated into a preliminary design. In the preliminary design, schematic drawings, principle schemes and broad system descriptions are made in order to provide an approximate view of the character, size, time and costs of the project. After the preliminary design is finished, the definitive design is made which captures the main measurements and most important materials and machinery in drawings calculations and specifications. The goal of this design is to create a clear view of the character, size, time and costs of the project. Finally, an execution design is made in which the location, size, materials and quality of the project is set (KIVI, 2001, pp. 26,27). This design is the input for the execution of the project and should therefore be of enough detail. As built drawings describe the project as it is eventually constructed.

These different phases of a design come with different levels of detail. A summation of the level of detail for each phase, based on expert interviews at Boskalis Nederland and assumptions from the description of KIVI, can be seen in Table 9. A reference design, which is often used by a client, is not described by KIVI, but is added to the table. This design can be defined as a rough sketch by the client for indicating its demands.

Name	**Level of detail**
Reference design	10%
Preliminary design	25%
Definitive design	75%
Execution design	95%
As built	100%

Table 9 – The level of detail per phase of the design

The table above shows the level of detail of a design. The levels of detail of a design are based on the design phases which are benchmarks widely used in the construction industry and described by KIVI.

The fact that assumptions are the basis for the level of detail described above makes these percentages not applicable for other research or reuse. However, because the percentages are merely used for a comparison, the use of these assumptions is valid.

Roughly, the level of detail for a project starts with a reference design by the client which is elaborated into a preliminary design at the end of the tender phase. The definitive design is made in the preparation phase, just as the execution design. The as built drawings follow at the end of the project.

A design for $System_{new}$ however does not merely have one single level of detail. A system is generally a combination of multiple products which on their turn can be divided into sub-systems. This can be visualized in a systems breakdown structure.

The several elements in a systems breakdown structure can be of different levels of detail. For instance, the level of detail in a civil structure could be much higher than the level of detail of a road connected to it while being part of the same project. A weighted summation of levels of detail of underlying elements has to be made in order to provide a single level of detail for the project. In order to do so, a weighting factor has to be incorporated in the equation. The contribution of the underlying elements in the systems breakdown structure to the parent system can be based on several aspects, namely value, complexity and complicacy. These elements will be regarded for calculating the weighting factor, as can be seen in the following table.

	Value	**Complexity**	**Complicacy**
Calculable	Calculation	Approximation	No
How	$V_{product}/V_{system}$	$C_{product}/C_{system}$	-
Concrete/abstract	Concrete	Abstract	Abstract
Based on perception?	No	Yes	Yes

Table 10 – The different approaches of a weighted summation of detail

The table above shows three possible approaches of a weighted summation of detail of underlying elements of the system.

Based on this table, a weighting factor based on value would be the most logical since it can be calculated very precise. However, the value of a part is not directly correlated to the extent in which a systems breakdown structure should be detailed. Furthermore, the value of $System_{environment}$ cannot be determined, making an equation for the entire project based on value difficult. Complexity of the system can be approximated, since it is based on abstract assumptions. Complexity is chosen for the approximation since this is believed to have the most influence on the level of detail of the system. The complexity of a system is based on the number of connections in the system and the complexity of the elements. Per element a complexity can be approximated based on the underlying elements (De Ridder, 2013, pp. 52,53). Hence, the level of detail of the new system can be approached by a weighted summation of the levels of detail of the underlying elements based on complexity in a systems breakdown structure.

The determination of the level of detail for $System_{environment}$ is more complex. Furthermore, it is too complex to breakdown the entire environment into a detailed structure. The level of detail for $System_{environment}$ therefore has to be an approximation of the extent in which the conditions of $System_{environment}$ is assured. It is therefore based on the knowhow of the surroundings, the number of soil measurements and the risk of differences in the soil conditions. For this research, the level of detail of $System_{environment}$ will be connected to the level of detail of $System_{new}$.

6.4.2 *The approximation of the level of detail*

The formulas for calculating the level of detail of the design will be elaborated in this paragraph. According to De Ridder, a project is a combination of a new system and an existing system in the form of the environment (De Ridder, 2013, p. 26). A project is therefore the result of the following equation:

$$Project \; = System_{Environment} + System_{new}$$

Hence, in order to be able to approximate the level of detail, we have to consider the level of detail of $System_{Environment}$ and the level of detail of $System_{new}$. Furthermore, the influence of both systems on each other has to be taken into account.

The equations which can be used for the approximation of the level of detail for the cases is described in this paragraph. As described in the previous paragraph, the level of detail is can be calculated by a weighted summation of the underlying elements. Therefore, the equation for the level of detail is defined as follows:

$$Detail_{new} = \sum_{N=1}^{N} \beta_N * \; Detail_{product_N}$$

$$Detail_{product} = \sum_{M=1}^{M} \beta_M * Detail_{subsystem_M}$$

$$Detail_{subsystem} = \sum_{K=1}^{K} \beta_K * Detail_{subassembly_K}$$

Etc. With

$$\beta_X = Complexity\ weighting\ factor\ of\ element_X \ \in \{0;1\}$$

The detail of the project can be approximated by a weighted summation of the detail of the new system and the detail of the existing system.

$$Detail_{project} = \alpha(Detail_{environment}) + (1-\alpha)\,(Detail_{new})$$

With

$$\alpha = weighting\ factor\ impact\ of\ system_{environment}\ on\ system_{new} \in \{0;1\}$$

Here, α, which is described as the influence $System_{environment}$ has on $System_{new}$ is dependent on assumptions. The value of α should be based on the type of project. When the project consists of tunnels, the influence of $System_{environment}$ on $System_{new}$ is much higher than when the project consists of maintenance of the top layer of the road.

Since the equations are now known, we can start approximating the level of detail for the cases in order to see the impact of the human factor on the projects. This will be done in chapter 7.

6.4.3 Potential origins for deviations between actual certainty and perceived certainty

As described in chapter 6.3.4, actual and perceived certainty potentially differ from each other. Perceived certainty about performance is certainty which the performance which is defined in the design is not assured or substantiated. This paragraph describes the potential causes which lead to a barrier for this assurance of the performance.

Problems can occur in the process for assurance of the performance or in the human influence on that process. The human influence can be divided into an individual impact or an impact resulting from an entire group.

An error in a process is a process description which does not suffice for the goal of that process. When regarding the design process, the goal is to deliver a design of a certain level of detail at a certain point in time which fulfills the client's requirements. When there is no link to the client's requirements in the design process whatsoever, the result will be a design which does not suffice for the goal of the process. These types of problems can be prevented by means of an adaption of the process description of the process itself.

Individual errors are errors which occur due to the influence of one person only and therefore problems which have not passed multiple feedback loops. An example of an individual error is a calculation error which is directly implemented into the design. These types of problems can be prevented by means of education or replacement of the employee.

Errors due to a group of individuals are problems as a result of the culture within an organization or a project team. An example of such an error is a project team in which an attitude of mind prevails in which the focus lies on easy construction instead of on construction according to the design. This way the design in which all requirements are incorporated can differ substantially from the executed project, leading to discussions with the client. These types of problems could be prevented by means of adaptions in the organizations culture or by strict guidance of a superior with an appropriate mindset.

An important awareness lies in the fact that an erroneous process does not automatically lead to problems. When the mindset of the project team focusses on the assurance of performance, but the process does not describe a proper means for doing so, the mindset might prevail over the proposed process. This will lead to assurance of the performance despite an erroneous process.

7. Problematic proceedings with requirements

The impact of interpretation on certainty in the five cases will now be considered based on problems which occurred in the process. This will be done for four measuring points; the start of the tender, the end of the tender, the end of the preparation and the end of the execution. These four measuring points are chosen since these points define the end of a specific phase of the project which leads to an accumulation of final documents. This allows the approximations to be more substantiated than during a phase.

7.1 The influence of perception on the cases

For all cases the level of detail will be calculated. After that, the deviation between the actual and perceived certainty will be approximated and the origins of these deviations will be described. The origins for the approximations are all based on interviews and internal documents and are elaborated per case. A different actual certainty from perceived certainty essentially means that the perceived extent of substantiated and assured performance is not equal to the actual extent of substantiated and assured performance, as has been elaborated in paragraph 6.3.

The first step of the analysis is to define the course of the level of detail of the design and the accompanied environment. After that, the deviations from perceived certainty will be described and finally, the origins for these deviations will be considered.

7.1.1 Approximated certainty for case 1

The process of case 1 altered from the standard process, since the execution was conducted four times. This paragraph merely describes the tender and the first preparation and execution process. The first case was based on small lifetime expanding maintenance of the roads where no structural adaptions had to be made, making the environment and its soil conditions less influential for the new system, resulting in an α of 10%.

Level of detail

At the start of the project, the character of the maintenance and therefore the contents of the project were fairly clear. Almost all types of maintenance to be conducted were known, so at the start of the project, the level of detail was at the level of a preliminary design of 25%. When the tender ended, the proceedings in the maintenance were defined so the detail rose above the 25% of the preliminary design. The performance however was not known sufficient to be at the level of a definitive design. It is estimated that the level of detail at this moment in time rose to approximately 40%. The end of the preparation resulted in work packages which described the tasks for execution, setting detail at the level of an execution design of 95%.

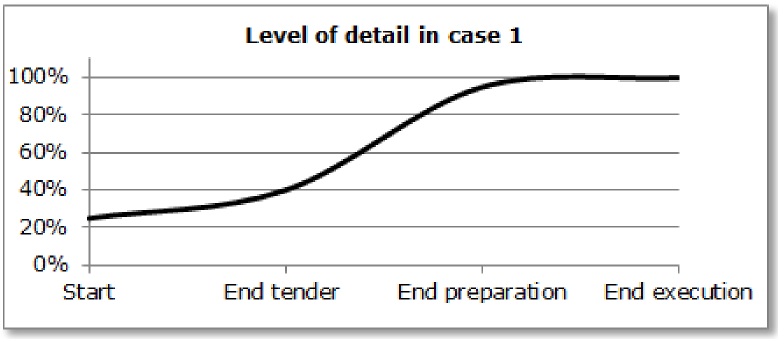


Figure 47 – The course of the level of detail for case 1 (own ill.)

This figure illustrates the course of the level detail throughout case 1 based on the values of detail at the measuring points. The level of detail at the end of the tender is already on 40% due to the maintenance character of the project.

Deviation from perceived certainty

Some elements of maintenance have accidentally not been taken into account in making the calculations in the tender. This has had a negative effect on the certainty of the entire project, since the prices were estimated too low. At the end of the design preparation and in the execution, there was no deviation between perceived and actual certainty.

Origins for deviations

An incomplete tender offer is not the result of a problematic process. The processes in the tender occurred as planned and the judgement whether all aspects of maintenance were incorporated was not linked to requirements nor was it the result of a standard process. The judgement whether the offer was complete was made by the responsible employee and had been confirmed by the direction. Hence, the problem therefore occurred due to an erroneous decision of an individual, but has not been corrected by the view of multiple employees, resulting in an origin in both the individual human factor as in the group.

			Phase				Origin		
			Start	End tender	End preparation	End	Individual	Group	Process
Case 1	$System_{new}$	The calculation was incomplete	-	x	-	-	x	x	-
	$System_{environment}$	-	-	-	-	-	-	-	-

Table 11 – The causes deviations from certainty and the origins for case 1

The table shows the phases in which the problems emerged and occurred marked with an "x". Also the origin for the problem is shown with an "x". The incompleteness of the calculation in case 1 has been the result of both the individual as the group.

7.1.2 Approximated certainty for case 2

The problems in the overall process which occurred in case 2 were the result of late adaptions by the client. The problems caused by the client are not part of the scope, hence it is not taken into account in the approximation. The second case was a large infrastructural project with several civil structures, making the environment of the project important for the results. Variable α is therefore set at 40% leaving a weighting factor for the design of 60%.

Level of detail

At the start of the tender, there was a reference design, setting the level of detail at 10%. At the end of the tender phase, the design was believed to be a preliminary design with a level of detail of 25%. The preparation phase ended with a definitive design instead of an execution design, setting the level of detail at 75%. The execution started with this level of detail, but as the construction changed from large soil replacement to more accurate construction, the designs were upgraded to a higher level of detail of 95%. So construction started with a level of detail of 75% which increased to 95% when needed.

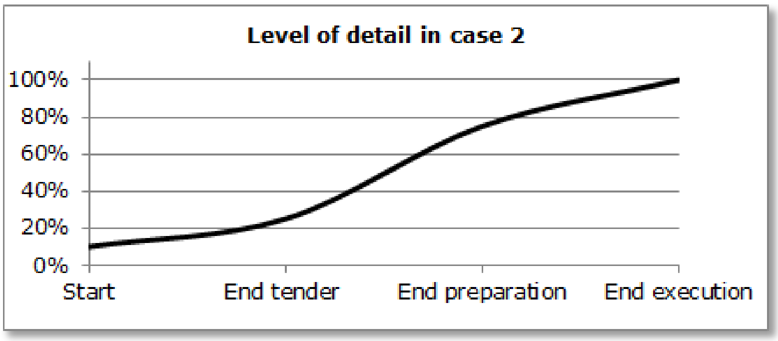


Figure 48 – The course of the level of detail for case 2 (own ill.)

This figure illustrates the course of the level detail throughout case 2 based on the values of detail at the measuring points. The level of detail at the end of the preparation phase was fairly low with 75%, but was increased to 95% during the execution when needed for the construction.

Deviation from perceived certainty

The design was based on soil conditions which had not been verified. These assumptions on soil conditions had influence on the entire project of civil structures and roads so the complexity of the products does not have to be taken into account. The impact of the assumptions on the design is estimated to have influenced both the tender and the realization phase. The fact that the soil conditions had been based on an assumptions has a large impact on the certainty on the environment.

Requests from municipalities had not been considered which has had an influence on the entire project. The impact of the future adaptions on the project is to influence the tender and the preparation phase. Since the responsibility for these adaptions lie with the client, these are not taken into account in the calculation.

Origins for deviations

The tender offer was constructed with biased input considering the soil conditions. The steps in the design process were followed, but the output was not as it should be. The design process does not describe a methodology for assessing the environment making it vulnerable to human interpretation. Furthermore, the design had passed multiple employees, which excludes the individual impact from an origin for the problems. There was however an attitude of mind which did not focus on the assurance of the performance of the environment. The process and the human influence of multiple individuals therefore are the origins for deviations of performance certainty.

			Phase				Origin		
			Start	End tender	End preparation	End	Individual	Group	Process
Case 2	$System_{new}$	The tender offer was based on assumptions on soil quality	-	x	-	-	-	x	x
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	x	x

Table 12 – The causes deviations from certainty and the origins for case 2

The table shows the phases in which the problems emerged and occurred marked with an "x". Also the origin for the problem is shown with an "x". The assumptions on the soil quality occurred in the tender and the preparation and have had a negative influence on the tender offer. This was the result of the lack of a process and the group mentality.

7.1.3 *Approximated certainty for case 3*

The process of the third project analyzed has proven to have occurred as is indicated in the standard process. The influence of the environment was important for the project, but no large civil structures had to be built on it, setting variable α at 30%.

Level of detail

The design started with a reference design with a level of detail of 10% which was translated into a preliminary design in the tender phase increasing the detail to 25%. In the realization phase, an execution design was made with a level of detail of 95%.

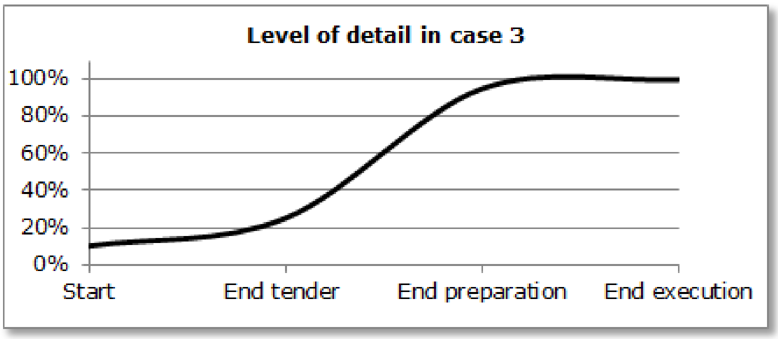


Figure 49 – The course of the level of detail for case 3 (own ill.)

This figure illustrates the course of the level detail throughout case 3 based on the values of detail at the measuring points. The levels of detail align with the course of detail as described in paragraph 6.4.1.

Deviation from perceived certainty

There was no difference between the perceived certainty and the actual certainty of the performance of $System_{new}$. The replacement of cables and pipelines however has delivered some problems in the realization phase. This has not been taken into consideration in the tender phase not in the preparation phase resulting in a negative impact on the certainty of $System_{Environment}$.

Origins for deviations

The replacement of cables and pipelines was the responsibility of the environmental manager. The process for the replacement of cables and pipelines describes detailed steps to be taken which should lead to a trouble free process. The fact that problems arose therefore is not a result of problems in the process, but a result of human influence. Since the responsibility for this process lies with the environmental manager, but has an interface with the designers, the origin for this problem emerges in both the individual human influence as in the group.

			Phase				Origin		
			Start	End tender	End preparation	End	Individual	Group	Process
Case 3	$System_{new}$	-	-	-	-	-	-	-	-
	$System_{environment}$	Problems occurred in planning the replacement of cables and pipelines	-	x	x	-	x	x	-

Table 13 – The causes deviations from certainty and the origins for case 3

The table shows the phases in which the problems emerged and occurred marked with an "x". Also the origin for the problem is shown with an "x". The problems concerning cables and pipelines replacement occurred due to the human influence, both individual as the group mentality.

7.1.4 *Approximated certainty for case 4*

An important alteration in the process in case 4 is the repetition of the phase in which a solution was created as the result of problems in the execution. Therefore, the preparation phase is described twice in this paragraph. In the fourth case, the environment has an important influence on the project since the design has to complement the original situation, setting variable α at 40%.

Level of detail

The project started with a reference design with a level of detail of 10% which was elaborated in the tender phase into a preliminary design with a detail of 25%. The design consisted of 2 dams and a repetitive element which had to be applied 253 times. The design for this element was standardized in a definitive design which went to the execution phase, setting the first level of detail at 75%. After problems occurred, the design was reconsidered and detailed into an execution design with a level of detail of 95%.

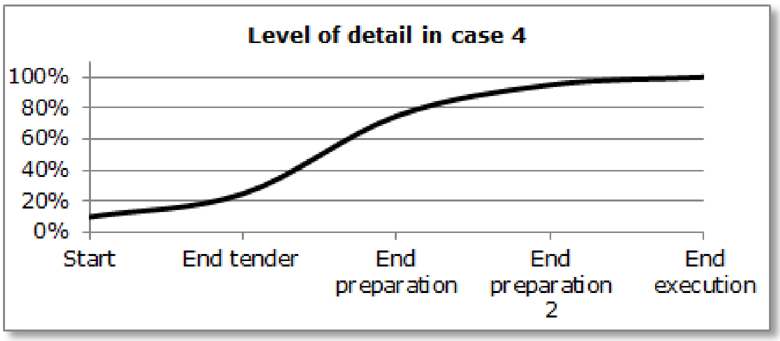


Figure 50 – The course of the level of detail for case 4 (own ill.)

This figure illustrates the course of the level detail throughout case 4 based on the values of detail at the measuring points. The figure shows that the preparation phase was ended twice. The first preparation phase resulted in a level of detail of 75% which was increased to a level of detail of 95% after the second preparation phase.

Deviation from perceived certainty

From the start of the project, assumptions have been made about the environmental condition which were the basis of several design decisions. The river control project consisted of a repetitive element and 2 main dams. The assumptions have been made on the repetitive element and have had a major influence since it concerned the connection of the element to the site. The impact is estimated to have a negative effect on the certainty of $System_{Environment}$ and on $System_{Environment}$ in both the tender and the preparation.

Furthermore, some of the requirements were not implemented in the design of the entire system, having a negative effect certainty in the tender phase.

In the realization phase, some of the design decisions from the tender were reconsidered and optimized. These optimizations were not in line with the client's requirements leading to a difference in perceived and actual certainty. The problems which resulted from these decisions had an influence on the entire system in the first preparation phase. These problems have not been solved after the second preparation phase.

			Phase					Origin		
			Start	End tender	End preparation 1	End preparation 2	End	Individual	Group	Process
Case 4	$System_{new}$	Not all requirements are incorporated in the tender offer	-	x	-	-	-	-	x	-
		The tender offer was based on assumptions on soil quality	-	x	x	-	-	-	x	x
		The design optimizations were not in line with the requirements	-	-	x	x	-	-	x	-
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x

Table 14 – The causes deviations from certainty and the origins for case 4

The table shows the phases in which the problems emerged and occurred marked with an "x". Also the origin for the problem is shown with an "x". The assumptions on the soil quality in the tender and the preparation phase were the result of the lack of a process and the group mentality. The assumptions also have had a negative influence on the tender offer. The group mentality furthermore resulted in the fact that not all assumptions were incorporated in the tender offer and that design optimizations were not always in line with the requirements.

Origins for deviations

All requirements have been registered into a software tool. The fact that not all requirements have been incorporated in the tender offer or that design optimizations were not in line with the client's requirements is not the result of a bad software tool or flaws in the design process since both worked and occurred as planned. The human influence however has a very important role in the problems. The software was not widely understood, so it was put aside, which means a deviation from the process. This has enabled multiple requirements to not be incorporated in the design or in the optimizations. The design has been reviewed by multiple employees hence the origin for this problem lies in the influence of multiple individuals.

The tender offer was constructed with biased input considering the soil conditions. The steps in the design process were followed, but the output was not as intended. As stated before, the design process does not describe a methodology for assessing the environment and therefore is vulnerable to human interpretation. The design had passed multiple employees, which excludes the individual human impact from an origin for the problems. There was however an attitude of mind which did not focus on the assurance of the performance of the environment. The process and the human influence of multiple individuals therefore are the origins for deviations.

7.1.5 Approximated certainty for case 5

An important alteration in the process in case 5 is the repetition of the phase in which a solution was created as the result of problems in the execution. Therefore, the preparation phase is described twice in this paragraph. The last case was a large infrastructural project with several civil structures, making the environment of the project important for the results. Variable α is therefore set at 40%.

Level of detail

The design started with a reference design from the client which was altered into a preliminary design at the end of the tender phase with a level of detail of 25%. The result of the first preparation phase was a definitive design of 75%, which was altered in an execution design with a level of detail of 95% in the second preparation phase after the reconsideration of the design.

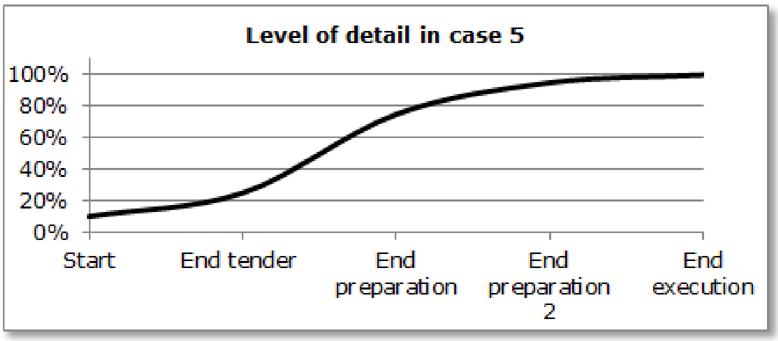


Figure 51 – The course of the level of detail for case 5 (own ill.)

This figure illustrates the course of the level detail throughout case 5 based on the values of detail at the measuring points. The figure shows that the preparation phase was ended twice. The first preparation phase resulted in a level of detail of 75% which was increased to a level of detail of 95% after the second preparation phase.

Deviation from perceived certainty

The design in the tender phase was based on assumed soil conditions which had impact on the entire system. This had a negative effect on the certainty of the design in the tender phase and the first preparation phase.

Furthermore, the fact that municipalities had to provide permits and that requirements from these municipalities could be added to the project was not taken into account in the tender phase. These added requirements eventually had a negative impact on the tender phase. The fact however, that solutions for these requirements were not discussed with the client and therefore conflicted with its purpose, makes that these requests from municipalities negatively influenced certainty of performance of the first and second preparation phase.

Problems about the timing of the replacement of cables and pipelines had not been taken into account in the tender phase, nor in the first and second realization phase. This had an impact on the entire system, since construction was delayed.

Origins for deviations

All client's requirements have been registered into a software tool. The client had the responsibility for the permits and therefore for the incorporation of the municipality's requirements. The issuing of permits however led to the introduction of new requirements by the municipalities in the project. The design was not always in line with the client's requirements due to fact that the requirements from the municipalities were introduced in the design without consultation of the client or the client's requirements. The deviations in certainty of performance therefore is not the result of a bad software tool or flaws in the design process since both worked and occurred as planned. The human influence of multiple individuals has eventually led to the incorporation of municipality's requirements in the design and therefore to the deviations of performance certainty.

The tender offer was constructed with biased input considering the soil conditions. The steps in the design process were followed, but the output differed from the intended output. The design process does not describe a methodology for assessing the environment and therefore is vulnerable to human interpretation, as is described in the elaboration of case 2 and 4. In this case, the design had also passed multiple employees, again excluding the individual human impact from an origin for the deviations. There was again an attitude of mind which did not focus on the assurance of the performance of the environment. The process and the human influence of multiple individuals therefore are the origins for deviations.

The replacement of cables and pipelines is the responsibility of the environmental manager, but has an interface with the designer. The process for the replacement of cables and pipelines describes detailed steps to be taken which should lead to a trouble free process, as has been stated in the elaboration of case 3. The fact that problems arose is not a result of problems in the process, but a result of human influence. Since the responsibility for this process lies with the environmental manager and has an interface with the designer, the origin for this problem emerges in the individual human influence as well as in the group.

			Phase					Origin		
			Start	End tender	End preparation 1	End preparation 2	End	Individual	Group	Process
Case 5	$System_{new}$	Incorporation of requirements by the municipalities in the design	-	-	x	x	-	-	x	-
		The tender offer was based on assumptions on soil quality	-	x	x	-	-	-	x	x
		The design decisions were not in line with the requirements	-	-	x	x	-	-	x	-
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x
		Problems occurred in planning the replacement of cables and pipelines	-	x	x	x	-	x	x	-

Table 15 – The causes deviations from certainty and the origins for case 5

The table shows the phases in which the problems emerged and occurred marked with an "x". Also the origin for the problem is shown with an "x". The assumptions on the soil quality in the tender and the preparation phase were the result of the lack of a process and the group mentality. The assumptions also have had a negative influence on the tender offer. The group mentality furthermore resulted in the fact that not all assumptions were incorporated in the tender offer and that design optimizations were not always in line with the requirements. The problems concerning cables and pipelines replacement occurred due to the human influence, both individual as the group mentality.

7.2 Comparing the cases

This paragraph will compare the information from the cases as described in the previous paragraph to each other. At first the levels of detail of all the cases will be summed up and visualized. Then, the impact of the level of detail on certainty will be described and the reasons and origins for the decline of certainty will be described.

As described in chapter 6.4, the minimal extent of detail in a design for a determined extent of certainty is the result of experience and knowledge of the team. It is therefore subject to the human influence. Table 16 shows the different levels of certainty of the five cases and is visualized in Figure 52.

Levels of detail	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Start	25%	10%	10%	10%	10%
End tender	40%	25%	25%	25%	25%
End preparation	95%	75%	95%	75%	75%
End execution	100%	100%	100%	100%	100%

Table 16 – The levels of detail of the five cases

The table above describes the level of detail of the five cases per measuring point. This table is visualized and explained in Figure 52.

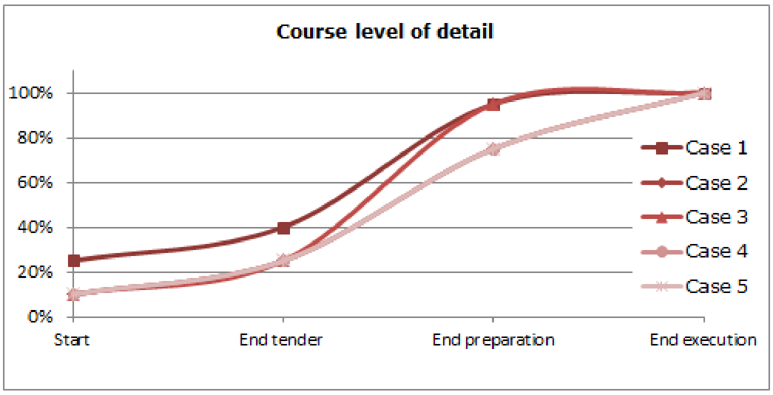


Figure 52 – The course of the levels of detail of all cases (own ill.)

This figure describes the levels of detail of all cases at the end of the different measuring points. All cases except for case 1 start with a level of detail of 10% which increases to 25% at the end of the tender phase. After that, case 1 and 3 end the preparation phase with a level of detail of 95%, where cases 2, 4, and 5 start execution with a detail of 75%.

The fact that the level of detail of all cases, except for case 1, at the end of the tender phase is at 25% indicates that the experience with projects alike is approximately the same for all cases, or that the certainty differs per case. The higher level of detail of case 1 merely exists because of the known maintenance character of the case.

The level of detail at the end of the preparation phase is higher for case 1 and 3, than it is for cases 2, 4, and 5. The level of detail at the end of the preparation has to be sufficient for construction which is 95%. The cases 2, 4, and 5 all started with a low level of detail leaving room for errors in execution. The level of detail in case 2 however increased during the execution process. The level of detail of case 4 and 5 was only increased after the works had been cancelled and the design was reconsidered.

From the levels of detail we can conclude that the experience with similar projects is the same for all cases, or that the certainty differs per case. Furthermore, the level of detail for the execution phase did not suffice for cases 4 and 5.

In order to consider the influence of errors in the levels of detail on the certainty of performance, a summation will be made of the origins for deviations from perceived certainty, as can be seen in Table 17.

Case	System	Cause	Phase					Origin		
			Start	End tender	End preparation 1	End preparation 2	End	Individual	Group	Process
Case 1	$System_{new}$	The calculation was incomplete	-	x	-	-	-	x	x	-
	$System_{environment}$	-	-	-	-	-	-	-	-	-
Case 2	$System_{new}$	The tender offer was based on assumptions on soil quality	-	x	-	-	-	-	x	x
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x
Case 3	$System_{new}$	-	-	-	-	-	-	-	-	-
	$System_{environment}$	Problems occurred in planning the replacement of cables and pipelines	-	x	x	-	-	x	x	-
Case 4	$System_{new}$	Not all requirements are incorporated in the tender offer	-	x	-	-	-	-	x	-
		The tender offer was based on assumptions on soil quality	-	x	x	-	-	-	x	x
		The design optimizations were not in line with the requirements	-	-	x	x	-	-	x	-
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x
Case 5	$System_{new}$	Incorporation of requirements by the municipalities in the design	-	-	x	x	-	-	x	-
		The tender offer was based on assumptions on soil quality	-	x	x	-	-	-	x	x
		The design decisions were not in line with the requirements	-	-	x	x	-	-	x	-
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x
		Problems occurred in planning the replacement of cables and pipelines	-	x	x	x	-	x	x	-

Table 17 – The summarized causes and origins for differences between certainties

The table above shows the deviations between performance certainty for $System_{new}$ *and* $System_{Environment}$ *and the reasons for these deviations. The boxes indicated with an "x" describe a direct influence. The boxes indicated with a "-" describe no influence. Furthermore, the impact of the deviation per phase of the project is shown and the origin of the deviation can be seen, as described in paragraph 6.4.3.*

From this table, the observation can be made that one aspect repeatedly emerges in the tender phase. Assumptions on the soil conditions are made in case 2, 4, and 5 without assessing risk. These assumptions have found their way into the designs of case 4 and 5, having a major impact on perceived certainty. These problems are the result a mentality in the tender team in which the incorporation and management of risk is not an intrinsic process. Furthermore, there is no process described in which the assessment of the environment is included. Therefore, problems which occur as the result of assumptions are the result of the lack of a process combined with the mentality of the team.

Another important origin for problems in the tender phase is the fact that requirements are erroneous incorporated into the design or are not incorporated at all. Furthermore, design decisions are made which are not in line with the requirements. In other words, the contractor fails to properly integrate the requirements into the design in the tender phase and therefore does not meet the contract. The origin of these problems lies in the tender phase

The replacement of cables and pipelines proves to result in problems in case 3 and 5 and is the result of individual human impact combined with the impact of the group, just as the incompleteness of the calculation in case 1. The individual creates an erroneous product which is not solved by the iterative feedback loops by the group.

When Table 17 is rearranged into the three clusters described above, the overview as can be seen in Table 18 emerges.

			Phase					Origin		
			Start	End tender	End preparation 1	End preparation 2	End	Individual	Group	Process
Case 2	$System_{new}$	The tender offer was based on assumptions on soil quality	-	x	-	-	-	-	x	x
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x
Case 4	$System_{new}$	The tender offer was based on assumptions on soil quality	-	x	x	-	-	-	x	x
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x
Case 5	$System_{new}$	The tender offer was based on assumptions on soil quality	-	x	x	-	-	-	x	x
	$System_{environment}$	The soil quality was different than assumed	-	x	x	-	-	-	x	x
Case 4	$System_{new}$	Not all requirements are incorporated in the tender offer	-	x	-	-	-	-	x	-
		The design optimizations were not in line with the requirements	-	-	x	x	-	-	x	-
Case 5	$System_{new}$	Incorporation of requirements by the municipalities in the design	-	-	x	x	-	-	x	-
		The design decisions were not in line with the requirements	-	-	x	x	-	-	x	-
Case 1	$System_{new}$	The calculation was incomplete	-	x	-	-	-	x	x	-
Case 3	$System_{environment}$	Problems occurred in planning the replacement of cables and pipelines	-	x	x	-	-	x	x	-
Case 5	$System_{environment}$	Problems occurred in planning the replacement of cables and pipelines	-	x	x	x	-	x	x	-

Table 18 – the rearranged table with summarized causes and origins for differences between certainties

This table shows the clusters of origins for deviations between perceived and actual certainty. The first cluster of origins is the result of assumptions that have a negative influence on the project which are not assured with risk caused by the lack of a process and the group. The second cluster of origins contains problems with processing requirements into the design in which the original contract is not considered as the result of a group mentality. The last cluster of origins consists of problems due to individual errors which are not corrected by other members of the team.

Since clusters of problems are now known, the problems can be elaborated in the next paragraph.

7.3 Causes for errors in perception

The most problematic cases, as is described in chapter 5, are case 4 and 5. The problems that have had an important impact in the cases influence the certainty as well as the level of detail. In this paragraph, the summation of problems will be indicated by 1-4, the summation of origins will be indicated by A-D.

The problem of (1) erroneous assumptions on the soil quality which have not been assured with risk has resulted in an invalid certainty and in problems in risk assessment. The (2) individual errors which have not been corrected in the process have also negatively contributed to an invalid certainty.

Problems resulting from (3) decisions which have not been in line with the contract have incorporated erroneous elements in the project, making the level of detail invalid. The (4) lack of a minimal level of detail has resulted in a delay in construction due to incomprehensible drawings for the execution team.

This paragraph describes the causes for these problems and the difference between mentality and experience.

7.3.1 Certainty and risk

The proceedings leading to problems in certainty and risk are elaborated in this paragraph. At first the causes for problem (1) will be described, after which the causes for problem (2) are considered.

In invalid certainty, perception differs from reality. An important cause for errors in the perception are assumptions which are regarded as certain later on in the project. In case 4 and 5, assumptions on the soil quality which have been made in the tender phase have been regarded as certain in later phases, leading to major problems in the project.

This problem (1) arose due to (A) the lack of a process in which the soil quality is assessed. At the start of the projects, the client provided some drawings which described the plan of the projects, but not the internal structure of the underlying soil. Assumptions were made about the quality of this underlying soil and were input for the designs. The fact that assumptions are made in the tender phase is not extraordinary, since the level of detail is not sufficient to be completely certain of all aspects of the project. Determining the quality of the soil conditions in the environment is difficult, since it is not possible to map the exact situation underground. The environment to build on is however an essential part of the project. The assessment of this environment is not described in the project management system and therefore completely the result of the estimation and experience of the individual. As a result of assumptions allowed by the previous, the perceived certainties for cases 4 and 5 were higher than the actual certainties.

Not only the impact of these assumptions, but also the risk connected to them should be taken in consideration in the project. The fact that no risk had been incorporated for the assurance of these assumptions has led to major problems. The process in itself is no guarantee for the prevention of these assumptions. The fact that the importance of assumptions and the potential negative impact has not been assessed is also the result of (B) a mentality which is not intrinsically risk-driven. When a risk-driven mentality had prevailed, the assumption would have been assured with risk, or the assumptions would have been noticed and tested in another phase.

The problem of (2) individual errors which have not been corrected later on in the project, has increased the difference between actual and perceived certainty. The individual errors all considered handling requirements and translating them into a solution. This solution however was not in line with the requirements, not due to a difference in interpretation between client and contractor, but due to human failure. Human failure is inevitable, and is therefore unavoidable, it can however be corrected. The (C) lack of a focus on the contract and the associated requirements, combined with an absence of an integrated approach is the cause for the absence of human failure being corrected. There is little insight in each other’s domain due to operative islands which are the result of functional barriers.

7.3.2 The level of detail

Problems in the level of detail can be found in the attainment of a minimal level and the validity of the detail. Problems concerning the validity of the detail are the result of (3) design decisions were not in line with the contract and the associated requirements.

Decisions which are not in line with the contract could be the result of an absence of a connection between the contract and the employee (in the form of systems engineering or software) or the result of a lack of focus on the contract by the employee. Since in all cases, the requirements have been implemented in a software tool, the employees have been connected to the contract. Problematic design choices emerge due to lack of verification of these design choices during the process. This occurs when the requirements are undervalued as the basis of the project, leading to optimizations which are not in line with the contract. Therefore, the (C) lack of a focus on the contract and the associated requirements, combined with an absence of an integrated approach, as described above, also has an impact on the validity of the level of detail.

The problems concerning (4) the lack of a minimal level of detail have delayed construction in cases 4 and 5. A low level of detail at the end of the tender phase should not automatically lead to problems, since the focus in the tender phase lies on increasing the level of certainty of performance. The design at the end of the preparation phase however has to be of sufficient detail for the start of the execution, since interpretation of the design could lead to decisions in the execution which are not in line with the requirements. The lower the level of detail, the higher the allowance of perception, the higher the risk the requirements are not met.

For cases 2, 4, and 5, the extent of detail which was achieved after the preparation phase was 75%, which is lower than the required 95%. In case 2, the low level of detail at the beginning of execution was sufficient for merely the start of construction. The level of detail was increased to 95% as execution proceeded. Since the level of detail increased when it was needed, the lower level of detail at the start of the execution has had no major impact on the project.

For cases 4 and 5, the execution design with a level of detail of 95% was made only after problems in the execution emerged. The level of detail has not been sufficient when the execution first started. There was a lot of room for interpretation of the designs and therefore room for errors leading to problems in delivery of the project.

The fact that the levels of detail at the end of the preparation phase are sometimes insufficient is partially the result of a lack of a set standard for the level of detail. The choice for the level of detail is the result of human interpretation of what is necessary. The design is a means of communicating to the execution team how to create what has been promised in the contract. The fact that the level of detail is not sufficient for the execution team, means that there is a (D) lack of attunement about the minimal level of detail needed for construction.

7.3.3 Experience and mentality

An important note is that inexperience with integrated contracts in the project team is not per definition a cause for problematic perception and therefore for failure costs. Cases 2, 3, 4, and 5 all worked with a team which had no or little inexperience with integrated contracts. A factor that is believed to be of major importance is whether the team embraced the integrated project approach which was the result of working with a new type of contract. In case 2 and 3 an attitude of mind prevailed in which the project had to be finished in collaboration with the client and in line with the contract. Furthermore, the promises made in the tender were guiding for the rest of the project. In case 4 and 5 problems concerning collaboration and working to the wishes of client and the contents of the contract prevailed. Decisions were regularly made without communicating with the client and promises from the tender were not automatically lived up to in the realization. There was no embracement of the integrated approach which was needed for a proper completion of the projects.

The project management team of case 4 and 5 had no experience in working with integrated contracts while there was experience in working with integrated contracts in case 1, 2, and 3. This lack of experience in cases 4 and 5 has had an impact on the mentality of the entire project team.

8. Preventing problematic proceedings and repeating the methodology

The proceedings with requirements that result in failure costs have been defined in the form of invalid and insufficient level of detail and invalid certainty which is not assured with risk. This chapter will describe a method for the prevention of these problematic proceedings after which the methods used for this research will be described in order to make it suitable for reuse.

In this chapter, the summation of problems will be indicated by 1-4, the summation of origins will be indicated by A-D and process interventions will be indicated by I-V.

8.1 Prevention of problematic proceedings

One of the problems that occurred in the cases originated due to (1) assumptions in the tender which were not assured with risk. Also, the lack of an integrated approach based on the contract in the tender and the preparation phase resulted in the absence of the discovery and correction of (2) individual errors in the project. Furthermore, (3) decisions were made which have not been in line with the requirements in the tender phase and the preparation phase. Finally, (4) the lack of detail for execution in the design has increased the room for interpretation in construction, therefore leading to problems. Solutions for the problems have to prevent assumptions on soil quality without the assessment of risk in the tender, aid in correcting individual errors, increase the project team's focus on the contract and the accompanied requirements and ensure a minimal level of detail at the end of the preparation phase.

As elaborated before, integrated contracts are fairly new in infrastructure construction. These integrated contracts are accompanied by new responsibilities in risk management and contract based operations. It is striking that the problems in the cases concern these new responsibilities. It indicates that these new responsibilities are not generally understood, not widely accepted or that the competences could be insufficient.

Solutions can be implemented top-down by a process intervention and bottom-up by a mentality adaption. The adaption of mentality is the result of organizational change which is widely described in literature. According to Harvard business review's 10 must reads on change management (Kotter & Cohen, 2011) the following steps are essential for proper organizational change.

1. Establish a sense of urgency
2. Form a powerful guiding coalition
3. Create a vision
4. Communicate the vision
5. Empower others to act on the vision
6. Plan for and create short-term wins
7. Consolidate improvements and produce more change
8. Institutionalize new approaches

The prevention of problematic proceedings resulting from the lack of focus on (B) risk and (C) the contract can be reached bottom-up by creating organizational change. The mentality adaption has to focus on the new contract forms, specifically on working risk-driven and contract-based. The means for achievement of such a change is not part of this research project and will therefore not be elaborated.

The top-down process interventions will be described next. A distinction can be made between substantive and reflective interventions. Substantive interventions concern changes within the processes where reflective interventions ensure the revision of processes or products. Another difference can be found between organizational and project based interventions. Project based interventions influence processes considering project management, where organizational interventions affect the organizational structures.

The description of the process interventions is done according to their influence on certainty and risk or on the level of detail.

8.1.1 *Certainty and risk*

As described in paragraph 7.3, the problems as a result of erroneous certainty have several origins, namely (A) the lack of a process which describes the assessment of the original situation, (B) a mentality with a lack of focus on risk, and (C) the lack of an integrated approach based on the contract.

Assumptions which have proven to be problematic have all been made in the assessment of the environment and the soil quality. The (A) lack of a process for this assessment results in an important role for expert judgement and therefore enables the origin of assumptions when this expert judgement is not available. A very clear method for avoiding these specific assumptions therefore is (I) the incorporation of the assessment of the environment and the soil quality into the project management system. This process starts with documents which are delivered by the client and have to be analyzed. The process should at least consider the current knowledge about the soil quality, the needed knowledge of the quality based on the possible problems that could occur and risk management. Furthermore, the result of the process for assessment of the soil quality has to be input for risk management, as well as for the design. The implementation of the assessment of soil quality helps preventing problematic assumptions on the soil quality. This intervention is a substantive intervention in the design process.

Another top-down process intervention which prevents unassured assumptions on soil quality, but also unassured assumptions in general due to (B) the lack of focus on risk is (II) demanding insight in the risk exposure of a project by the company management. The insight should contain the means which have been used for the incorporation of risk in the project and not merely a risk register. It should focus not only on external risk, but also on risk from individual choices. This interventions forces the discussion about the means for incorporation of risk in the project. It is an organizational reflective intervention since it requires the management to reflect.

Another process intervention focusses on interface management and risk assessment for the creation of an integrated approach based on (B) risk and (C) the contract and its accompanied requirements. The goal is to (III) periodically organize combined risk-interface sessions in which employees (responsible for the definition of time, quality and costs from a single management layer) discuss the course of the project and potential problems. This will lead to insight in each other’s domain and dissolve operative islands which result from functional barriers. The awareness of overlap in risk and responsibility will lead to a more integrated approach. This intervention is a substantive intervention in a project process, namely the processes for risk and interface management.

8.1.2 *The level of detail*

Problems considering the level of detail are the result of (C) the lack of an integrated approach based on the contract and (D) the lack of attunement about a minimal needed level of detail.

The (III) periodical organization of combined risk-interface sessions in which employees discuss the course of the project and potential problems also has an important impact on the level of detail. It potentially prevents (3) design decisions which are not in line with the contract by creating multiple viewpoints and therefore contributes to a valid level of detail.

Another solution for the prevention of (3) design decisions which are not in line with the contract can be found in verification. When a requirement is allocated in a design and discarded after this allocation, the requirements will not be taken into account when the design is optimized. The (IV) verification of requirements after adjustments in the contract, the design or the processes should prevent these problematic optimizations. This intervention is a substantive intervention in a project process, namely the systems engineering process. A suitable solution can be found in the application of software in which requirements can be allocated to an object and remain connected after the requirement has been verified.

The (D) lack of attunement about the minimal level of detail needed for construction can be solved by the creation of an internal client for the designer in the form of the main executor. As stated before, the goal of the design is to ensure that the execution will occur as promised in the tender. Therefore, the designer should translate the promise into a practicable drawing for the executor. Agreements about the level of detail of the design between the designer and the main executor will help in reaching a level of detail which is needed for construction. The transfer of the design from designer to the executor has to be a formal transfer in which the executor verifies the level of detail of the design. This way, the level of detail is tuned to the executor and the minimal level has to be reached before a transfer occurs and thus execution can start. (V) Formal agreements about a minimal level of detail between the executor and the designer at the beginning and end of the design phase will prevent (4) the lack of level of detail at the end of the preparation due to the (D) lack of attunement about the minimal level of detail needed for construction. The intervention is made in the project processes of design and execution. It can be seen as a substantive intervention from the designer's perspective, and as a reflective intervention from the executor's perspective.

8.1.3 The summarized overview of problems, causes and process interventions

<table>
<tr><th></th><th colspan="2">Problem</th><th colspan="2">Cause</th><th colspan="2">Process intervention</th></tr>
<tr><td rowspan="4">Certainty</td><td rowspan="3">1</td><td rowspan="3">Assumptions on the soil quality without the assurance through risk assessment</td><td>A</td><td>The lack of a process which describes the assessment of the original situation</td><td>I</td><td>The incorporation of the assessment of the environment and the soil quality into the project management system</td></tr>
<tr><td rowspan="2">B</td><td rowspan="2">A mentality which is not intrinsically risk driven</td><td>II</td><td>Demanding insight in the risk exposure of a project by the company management</td></tr>
<tr><td rowspan="3">III</td><td rowspan="3">Periodically organize combined interface sessions in which employees (responsible for the definition of time, quality and costs from a single management layer) discuss the course of the project and potential problems</td></tr>
<tr><td>2</td><td>Individual errors which are not corrected by iteration</td><td rowspan="3">C</td><td rowspan="3">The lack of a focus on the contract and the associated requirements as the base of the project combined with a lack of an integrated approach</td></tr>
<tr><td rowspan="3">Level of detail</td><td rowspan="2">3</td><td rowspan="2">Design decisions in the preparation phase which are not in line with the contract</td></tr>
<tr><td>IV</td><td>Verification of requirements after adjustments in the contract, design or processes</td></tr>
<tr><td>4</td><td>The lack of a level of detail in the design at the end of the preparation phase</td><td>D</td><td>The lack of attunement about the minimal level of detail needed for construction</td><td>V</td><td>Formal agreements about a minimal level of detail between the executor and the designer at the beginning and end of the design phase</td></tr>
</table>

Table 19 – The connections between problems, causes and solutions

The table shows the direct connection of the problems, causes and process interventions and the impact on certainty or level of detail, as has been described in this paragraph.

An overview of the problems, causes and process interventions and how they are connected can be found in Table 19.

The top-down process interventions will potentially contribute to the reduction of the failure costs as a result of problematic handlings with requirements which have been analyzed in the five cases. A combination of the top-down process interventions and the bottom-up mentality adaption will strengthen the reducing impact on failure costs, but will not mitigate infrastructure failure costs entirely, as a result of the narrow scope of the research.

8.1.4 *Application of the V-model with certainty and level of detail*

The V-model with certainty and level of detail as can be seen in Figure 46 is applied for the analysis of projects that have already passed. The analysis with this model has made the impact of problems comprehensible in both the level of detail and the certainty and furthermore described their effect on the project results. It would be interesting to be able to use the model not only for looking back on what went wrong, but also to indicate the course of and problems in the projects. This chapter describes the methods for doing so.

As described in paragraph 6.4, the goal of the preparation phase during the tender is to create a degree of certainty sufficient for the tender offer. The goal of the preparation phase during the realization is to increase the level of detail to an extent which allows the construction of promises from the tender offer.

The extent of certainty of performance which is needed at the end of the tender has to be known even before the process starts. This determines the goal of the tender and thereby indicates the extent of certainty of performance that has to be increased. The means for achieving the set level of certainty have to be determined based on the knowledge of projects alike, experience of the project team, and other subjective elements. These means can be translated into the level of detail of the environment and the design that is needed for the set extent of certainty of performance. A combination of a systems breakdown structure and formula that has been used in this research:

$$Detail_{project} = \alpha(Detail_{environment}) + (1-\alpha)\,(Detail_{new})$$

is suitable for determination of the level of detail needed for this set extent of certainty of performance. The budget and planning have to be based on this certainty of performance. The extent of risk that remains as a result of this process has to be incorporated into the budget or the planning.

When the project is awarded, the offer has to be elaborated into a plan for execution in which time, budget and performance are incorporated. This means that the level of detail has to be increased to a level which is needed for construction and that the budget and schedule have to be aligned to it. The systems breakdown structure provides a means for the calculation and therefore a means for the determination of the level of detail at a given moment in time. The equation can therefore be used for measuring the process, and the work to come, for completion of a specific phase.

Concluding, the model provides insight in the relation between the processes, the level of detail and the extent of certainty. It also aids in understanding the impact of problems and errors in the level of detail on certainty and risk. The extent of certainty of performance needed in the tender has to be known at the start of the project, since it indicates the goal of the tender process in general.

The level of detail needed at the end of the preparation has to be known at the start of the design phase as an agreement between the executor and the designer, since it indicates the minimal demands of the preparation phase. The equation stated before helps providing insight in the extent in which the level of detail is reached. This is visualized in Figure 53 on the following page.

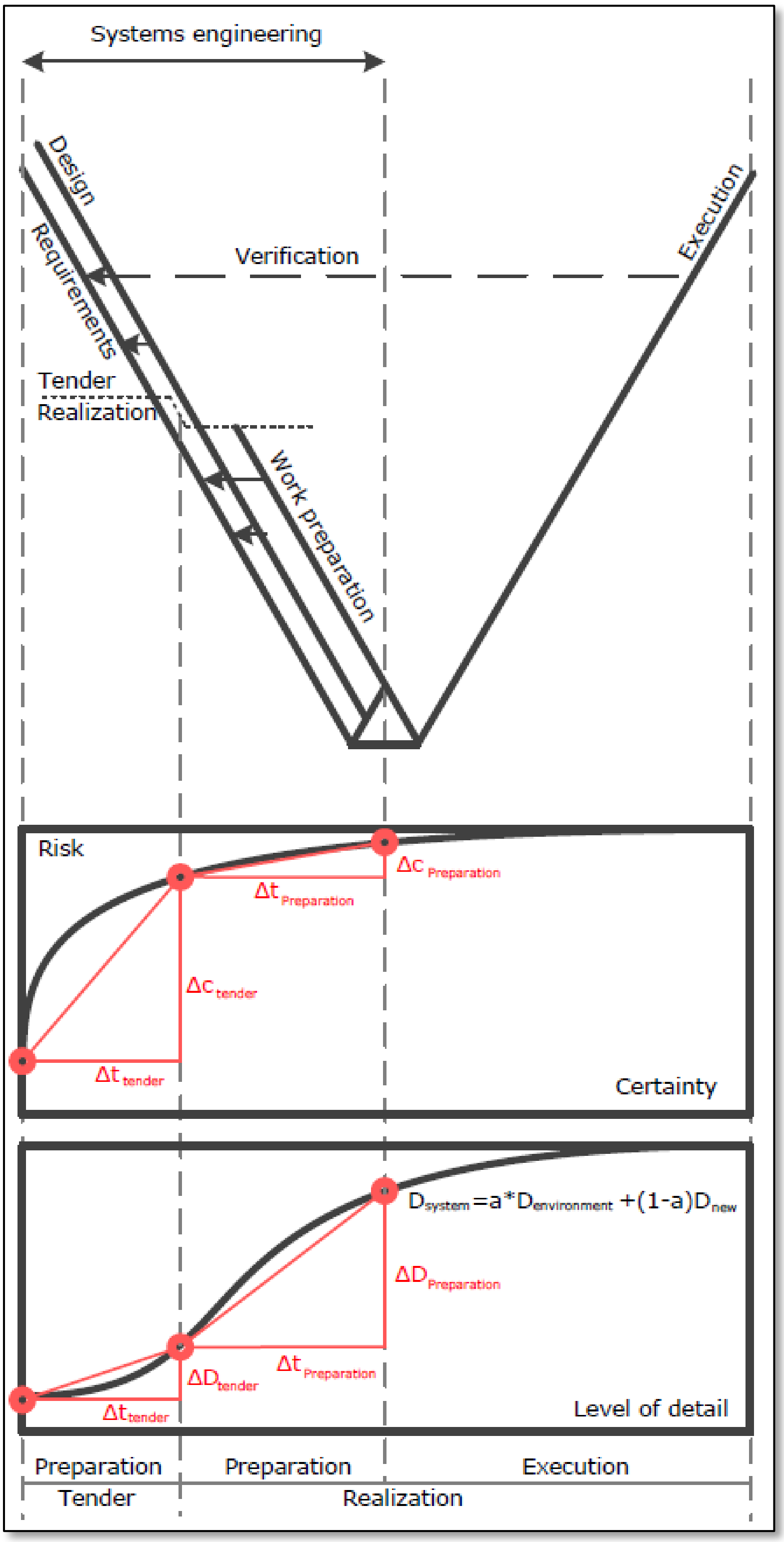


Figure 53 – The use of the V-model with certainty of performance and level of detail (own ill.)

The figure shows the V-model combined with the certainty of performance model and the level of detail. The level of detail can be calculated based on the formula described in paragraph 6.4.2. The difference in time (Δt), detail (ΔD) and certainty of performance (Δc), are shown in the model. These entities have to reach a value which *has been set at the start of a project. This helps determining the extent of work to do for completion of the specific phase to a predetermined value.*

The methods for prevention of problematic proceedings with requirements, which have been described above, will contribute to a valid level of certainty with accompanied risk management and a minimum level of verified detail.

8.2 Repeatability of the methodology

The methodology used for this research can be used again for the analysis and recommendations of other projects. In order to do so, the steps that have been taken in this research will be reconsidered. The process can be divided in two main steps. The first step designates the problematic processes in the projects. The second step analyses the human impact on the projects.

An important aspect of the methodology is the narrowing of the scope. At first, a scope considering all processes is considered which is later on narrowed down to merely the problematic processes with requirements by the completions of the first step of the research. The reason for this approach is that it allows the researcher to understand the entire project before a more specific part of the process is investigated. It allows an integrated view of the project.

To start the research, models for the assessment of the processes are created. In this case, since the research considered the origins for failure costs as a result of proceedings with requirements in infrastructure construction, a standard process in infrastructure construction was made and potential causes for failure costs from literature were considered. The standard process has been visualized based on the IDEFØ methodology.

When the standard process and the potential causes for failure costs are known, the data to be analyzed by these models can be collected. The information from the projects can be collected from interviews and documents. The interviews provide a potential course of progress of the project which can be substantiated by other interviews and project documents, such as the contract, the list of requirements, verification reports, examination reports, the project management plan, minutes from meetings between the client and the contractor, etc. Based on this information, the processes of the cases are compared to the standard process and the potential causes for failure costs. The deviations from the process and the causes for failure costs can be designated leading to an overview of problems in the case.

Since the problems in the cases are now known, the second step can be taken in order to understand the impact of the problems and also narrow down the scope. For doing so, a model has to be constructed considering all problematic proceedings with requirements. When all the processes are integrated in the model, the human influence is connected to it. The V-model combined with the level of detail and the certainty sufficed for this research. Other models which can be used for the description of problematic processes which handle requirements have been elaborated in paragraph 6.1. A description of the approximation of the human influence on the process has to be incorporated in this step since this allows a more substantiated comparison of the projects. For this research, the human influence on the process has been integrated by means of the calculation of the level of detail and a description of the influence of problems in the level of detail on certainty of performance.

Now the impact of these processes on certainty and the level of detail is known, the level of detail for all cases can be calculated to form a basis for the second comparison of the cases. Furthermore, the deviations between actual and perceived certainty of performance and the origins of these deviations can be described. The comparison of all levels of detail and all deviations from certainty then has to be clustered where possible in order to define the origins for the problems. Finally, recommendations on these origins for problems can be described from there.

Concluding, the first step is to define the problematic processes. This can be done by the creation of standard models to which the data that results from interviews and internal documents can be compared. The second step is to define which proceedings are problematic by creating a model in which processes from the first step that handle requirements are connected to the human influence. The comparison of the approximations of the human influence per case leads to a clustering of origins of problems based on which recommendations can be made.

8.3 Validity of the research

This paragraph describes the validity of the problems, origins and solutions which have been stated above by considering the extents of validity as has been specified in paragraph 2.7.

Construct validity is reached by operationalizing definitions and models specifically for this research, such as the standard process, the V-model and the equation which is used in the V-model.

Internal validity is partly reached by connecting the human influence to the problematic processes by means of actual and perceived certainty. The conclusions which followed from this causal connection however, lack validation. The conceptual model posed in paragraph 8.1 could be validated by the application of the conceptual framework to an actual project. Since this application would take at least a year, this is not part of the report. The validation that was possible was the validation by discussion of the model and therefore by expert reviews. Several employees from Boskalis Nederland, including a design manager, risk manager, systems engineer, safety-health-environment-quality manager, tender manager, project managers, head of the business office, and a CFO have seen and approved the model and the methodology accompanied by it. Furthermore, they agreed with the causal relation between the causes and the problems and indicated the recommendations as helpful.

Potential repeatability of the research adds to external validity and reliability. The methodology substantiated by the instructions for reuse in chapter 8.2, combined with the case study protocol, makes the process reproducible.

The findings of this research however, are based on five embedded cases, which is not enough for a generalization over the entire contractor market. External validity is therefore merely applicable for projects based on integrated contracts at Boskalis Nederland. Furthermore, the results are based on interpretation of the cases. Even though multiple interviews were substantiated with project documents in order to obtain an objective view on the cases, the analysis is still vulnerable to interpretation of these interviews and the documents by the researcher.

9. Conclusions, recommendations, implications and reflection

This chapter will conclude the research and will provide recommendations. The conclusion will answer the research question and check whether the objective is met. The research question was stated in paragraph 2.1 as follows:

> Research question
> *Which proceedings with client's requirements, from requirement specification to completion, are responsible for failure costs and how can these proceedings be improved?*

The sub questions which have been used to answer the research question have been defined as follows:

1. What are the problematic processes at Boskalis Nederland per case based on (a) a comparison between the course of the projects and a validated standard process and (b) a comparison of this course to potential causes for failure costs from literature?
2. What is the impact of human handlings in the problematic processes at Boskalis Nederland which handle requirements and how can this be visualized in a model?
3. What is the human influence per case and how do the influences per case compare?
4. Which causes for failure costs are assignable to the cases based on the analysis and what are the origins of these causes?
5. How can the analyzed failure costs be prevented?

The answers to sub questions 1, 2, and 3 describe the results per case.

The problematic processes in the cases are systems engineering, design, chance/risk, management, interface management, organization management, cables and pipelines, verification process, execution, and environmental findings. The impact of the human handlings has been introduced by connecting certainty of quality and the level of detail to the model. The human influence per case can be summarized as the interpretation of certainty and the way in which risk is managed on the one hand and the decision for a minimal level of detail with requirement based decision-making on the other.

Sub questions 4 and 5 aid in answering the research question and are both answered in paragraph 9.1. The conclusion should meet the research objective, which has been stated as follows:

> Research objective:
> *Provide recommendations on improved proceedings with requirements following from the client's request, in integrated infrastructural contracts, in order to reduce failure costs.*

9.1 Conclusions

When considering large infrastructural projects, the goal of the tender phase is to obtain certainty about the means for achieving the client's normative quality while incorporating the remaining uncertainty as risk. The goal of the preparation phase is to reach a level of detail in the design which allows the executor to realize the normative quality. A valid extent of certainty and detail is evident.

Following from the analysis, the problematic proceedings with requirements leading to failure costs at the end of the tender phase are (1) assumptions, for instance on the soil quality, which are not assured with risk and (2) individual errors which are not corrected in iterative processes, leading to invalid certainty and improper risk assessment. Problematic handlings which arise at the end of the preparation phase are (3) an insufficient level of detail for construction and (4) design decisions which are not in line with the contract, leading to an invalid level of detail.

The origins of these problems are (A) the lack of a process which describes the assessment of the soil quality, (B) a mentality which is not intrinsically risk-driven, (C) the lack of a focus on the contract and the associated requirements as the base of the project combined with a lack of an integrated approach, and (D) the lack of alignment about the minimal level of detail needed for construction.

Solutions to these problems can be top-down process interventions or bottom-up mentality adaptions. The top-down process interventions force the use of a methodology onto employees by means of project or organizational intervention. The intervention can be substantive or reflective. The bottom-up mentality adaptions make that the methodologies are widely accepted and intrinsically applied.

Mentality adaptions that contribute to the reduction of failure costs as a result of proceedings with requirements have to focus on working with new contract forms, more specifically on working risk-driven and contract-based. This can be reached through application of organizational change focusing on risk- and contract-driven decision making. The means for achieving this mentality adaption are not part of this research.

Process interventions that contribute to the prevention of failure costs as a result of proceedings with requirements, consider the (I) incorporation of the assessment of the environment and the soil quality into the project management system, (II) a demand of insight in risk exposure by the company management, (III) periodical combined interface sessions, (IV) repeating verification after adaptions in the contract, design or processes, and (V) making formal agreements about a minimal needed level of detail. The connection between the problems, causes and process interventions have been visualized in Table 19.

A combination of these top-down process interventions and the bottom-up mentality adaption will contribute to the prevention of the failure costs as a result of problematic handlings with requirements which have been analyzed in the five cases.

9.2 Recommendations

This paragraph provides recommendations for coping with the conclusions and recommendations for future research.

9.2.1 Recommendations based on the research

The recommendations following from the research are to first apply the quick wins in the form of the top-down process interventions. The process interventions have been summed up as (I) the incorporation of the assessment of the environment and the soil quality into the project management system, (II) demanding insight in the risk exposure of a project by the company management, (III) periodically organize combined interface sessions in which employees (responsible for the definition of time, quality and costs from a single management layer) discuss the course of the project and potential problems, (IV) verification of requirements after adaptions in the contract, design or processes, and (V) ensuring formal agreements about a minimal level of detail between the executor and the designer at the beginning and end of the design phase. Furthermore, it is recommended to use the V-model with the level of detail and the certainty of performance and the equation for the level of detail for monitoring the projects.

In the long run, mentality adaptions which can be reached through organizational change focusing on risk- and contract-based decision making will contribute to the prevention of failure costs resulting from proceedings with requirements. A more elaborate description of the reasons behind these recommendations can be found in paragraph 8.1.

The mentality adaptions focus on risk- and contract-based decision making, which are both relatively new contractor responsibilities in infrastructure construction. For a contractor, the old method of working was based on the construction of an execution design from the client. Everything that was not, or erroneous incorporated in the design was considered to be a risk for the client and a benefit for the contractor due to more work. In the new, integrated contracts, the responsibility for designing according to the contract, and therefore for dealing with the accompanied risk, has shifted from the client to the contractor. This new responsibility for the contractor means a completely new approach of projects.

It is striking that the biggest problems leading to failure costs in the analyzed five cases have been found in the contractor's new responsibilities. The research focused on the problems that occurred in the cases, but did not take into account the role of the organizational change as a result of new integrated contracts on the mentality of the employees.

No conclusions can be drawn considering the causes for the lack of risk- and contract-based mentality. The following paragraph will therefore recommend possible further research, also taking into account these causes.

9.2.2 Further research

At first, it is recommended that further research considers the causes for the mentality which is not intrinsically risk- and contract-driven. Furthermore, the result of a change in working methods as a result of the rise of integrated contracts should be investigated.

It is furthermore recommended that further research is done on the methodology of approximating certainty of performance in infrastructural projects during the process. The certainty of performance in this research is considered to be a subjective result of the experience and knowledge of the project team. A method for approximation of the certainty of performance in a project would strengthen the monitoring quality of the model and could make the preparation process more data driven. Furthermore, research should be done for a methodology which describes the certainty of the project, not only of the performance.

Furthermore, research can be done on the moment in time when it is noticed that a project does not proceed as planned. When problems originate in the tender phase, but are noticed in the execution, a method can be conceived that focusses on the prevention of these failures early in the process.

Also, it would be interesting to see how much risk can be reduced by how much increased level of detail between different milestones during tender and preparation. In this way a company is better able to know to what extend they have to design per phase and what resources/cost are required.

Further research can also be done on the means for defining and providing insight in the quality of the environment. This would strengthen the equation used for the level of detail in this research making it more suitable for monitoring projects.

9.3 Reflection

This paragraph describes the theoretical contribution of this research and reflects on the used method. Furthermore a reflection will be described on the cases.

9.3.1 Reflection on the theoretical contribution of the research

The theoretical contribution of this research can be based on the results of the research and on the methodology of the research. Both find their origins in literature. The literature studies conducted for this research focused on a standard process (paragraph 4.1), the potential origins for failure costs (paragraph 4.2), certainty (paragraph 6.3) and the level of detail (paragraph 6.4). The first two subjects have merely been used for narrowing the scope; the research has not contributed to literature on these aspects. The last two subjects have been used to create a model in which the human influence in projects and the origins for failure costs can be analyzed. The contribution to literature of the result and the methodology will be described next.

The result

The result of this research was to assign the causes for failure costs to a specific set of projects in order to determine a strategy for coping with them. The contribution to literature therefore has nothing to do with the outcomes of the research.

A widely spread set of causes for failure costs is already described by literature. These causes differ per research, even within the Dutch dry infrastructure sector (USP Marketing Consultancy bv, 2010) (Koning & Van Elp, 2011). Expanding or confirming the already vast and extensive list of causes for failure costs therefore would be as carrying coals to Newcastle.

Furthermore, the research consists of five projects in two different sectors of infrastructure construction at a single contractor. This makes the application of a statistical analysis impossible. The results of the research cannot be generalized to a specific branch of construction. Also, the research is based on interviews and project documents with a lack of quantitative data making the results of the research difficult for reuse. The extent of interpretation of not only the interviewed, but also of the questions by the interviewee make the results difficult to generalize for the construction industry. Finally, the fact that parts of the obtained data originate from interviews and the fact that the internal documents are confidential for Boskalis Nederland, makes reproducibility difficult. The results of the research therefore do not contribute to literature.

The methodology

In contrast to the results, the method is suitable for reuse and can be considered the contribution to literature. The model that was used (Figure 46) for obtaining the results is new in the analysis on failure costs in infrastructure construction. The approach in which the human influence is regarded in combination with processes with requirements is a completely new way of analysis. The connection between this human influence and the processes which handle requirements is visualized in a V-model to which the level of detail and the certainty of performance are connected. The theoretical contribution of the research can be found in this alternative method for the view on failure costs. The model enables users to find their own problematic processes and handlings, instead of filtering from a standard list of possible origins. The potential reuse of this model as a method for analysis has been described in paragraph 8.2.

9.3.2 Reflection on the method

The research consisted of two process loops. The loops start with a literature study after which the contents of the literature study are translated into a model making it ready for analysis. After execution of the analysis with this model, the data is processed. This reflection will first describe the two loops, considering the method within a loop, the motivation and validity of the method and the potential improvements. Finally, a reflection on the method in general will be provided.

Research loop 1

The goal of the first loop was to assign the problematic processes in the cases. The scope entailed the entire course of the project in order to ensure a clear integrated view of the cases. The analyzed literature focused on the course of a construction project and on causes for failure costs. The choice for the subjects of the literature study was based on the exploratory character of the research. Since there was no indication which processes were problematic and potentially led to failure costs, the most logical step was to consider all of the processes. The course of a construction project has been translated into model for analysis, the causes for failure costs have been summarized. The analysis of the cases occurred based on this model and summation. The research on problematic processes combined with previous investigations on failure costs had led to the designation of the problems in the cases and therefore the potential causes for failure costs. These were input for the following loop. The fact that two approaches have been used for the designation of these processes increases the validity of the results.

On the other hand, only two methods have been used for de designation of problems in the projects. The analysis on problematic processes could have been increased by focusing on communications, project management structures, the level of experience of the employees, organization management, etc. Another restriction in the first loop can be found in the standard process. It is attributable to Boskalis Nederland, since the process is based on their project management system. Other contractors probably use comparable methods, but there will potentially be differences, making the standard process less suitable for other contractors.

Research loop 2

From the analysis of the problematic processes, a method has been developed explicitly for research on the 5 projects at Boskalis Nederland in loop 2. The scope for the second loop narrowed down to the problematic processes considering requirements. The goal was to assess the problematic handlings with requirements in the cases. The literature study focused on certainty, uncertainty and risk, and the level of detail in the projects since the main goals of different phases of the project are described in these aspects. Based on this literature study, a model was created for the analysis of the projects. After the analysis, the problematic processes with requirements in the five cases could be distinguished.

The usability of the method exceeds these 5 specific cases and potentially Boskalis Nederland. It describes the design process of a project based on requirements. An important aspect of the method is the visualization of the influence of decomposition and integration of the requirements on the level of detail of the design and the certainty of the performance. The method described in this model is therefore suitable for not only Boskalis Nederland, but for design projects based on requirements in general.

The method in general

The choice for the two loops has been based on the exploratory character of the research. The goal of the research was to designate problematic handlings with requirements. The first loop decreased the processes to consider for the analysis of the handlings within the processes. It therefore helped narrowing down the scope and keeping the research manageable.

The validation of the method and the outcomes was based on expert reviews within the organization at which the research took place. This enables a potential bias in the validation. The validation would have been stronger when the validation was based on expert reviews from organizations which have had nothing to do with the research.

9.3.3 Reflection on the cases

The selection of the cases has been based on an analysis of projects that were in execution and almost ready to deliver the project to the client. This way, the information of the projects would still be available and the employees would remember what has occurred at the projects. This has led to a list of 44 projects which was narrowed down by selecting only integrated projects with a minimal budget of 10 million. Furthermore, the share of Boskalis in the projects had to be at least 50%. These selection criteria led to the five cases which have been analyzed.

These five embedded cases have been compared to each other leading to sufficient correlation to designate the origins for failure costs with a reasonable certainty. However, the fact that five cases from specific sectors at Boskalis Nederland have been analyzed suppresses the extent in which the conclusions can be generalized within the market of contractors, but also at Boskalis Nederland.

The more cases are analyzed, the more the conclusions are supported. Given the size and timeframe of the research, the analysis of more than five cases was unrealistic. The fact that five cases have been analyzed increases the concluding strength of the research, but does not deduct the need for prudence in considering the outcomes of the research.

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Appendix I – Case study protocol

This appendix describes the case study protocol which is used for conducting the embedded case studies. Paragraphs which overlap with the methodology of the report are omitted.

This protocol is an addition to the research proposal for a process which improves problematic proceedings with client requirements resulting in failure costs at Boskalis Nederland. It focusses on the role of embedded case studies in the research. This protocol is written as an addition, and is not incorporated in the proposal, since the level of detail of the protocol does not correspond to the level of detail of the proposal. Furthermore, the protocol is used for only part of the research process, and is therefore considered an appendix.

At first, it is helpful to determine the definition of a case study. According to yin, a case study can be defined as follows:

> Definition case study:
> A case study is an empirical inquiry that (1) investigates a contemporary phenomenon within its real-life context, especially when (2) the boundaries between phenomenon and context are not clearly evident. The case study inquiry (3) copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result (4) relies on multiple sources of evidence, with data needing to converge in a triangular fashion, and as another result (5) benefits from the prior development of theoretical propositions to guide data collection and analysis.
>
> (Yin, 2003, pp. 13,14)

In other words, the case study as a research strategy comprises an all-encompassing method covering the logic of design, data collection techniques, and specific approaches to data analysis. In this sense, the case study is not either a data collection tactic or merely a design feature alone but a comprehensive research strategy (Yin, 2003, p. 14).

The protocol for executing such a case study is a major way of increasing the reliability and is intended to guide the investigator in carrying out the data collection from a single case study (Yin, 2003, p. 67).

The goal of the embedded case studies is to provide information about the proceedings with requirements at Boskalis Nederland throughout the entire process from contract to product and determine which proceedings have the most impact in terms of failure costs. The objective of this research can thus be stated as follows:

> Case study objective:
> *The objective of the case studies is at first is to confirm the problem definition and furthermore to expose the dominant factor in failure costs by thoroughly analysis of the information resulting from the case studies.*

The emphasis is on the proceedings. The research question for reaching this objective is defined as follows:

> Case study research question:
> *Which proceedings at Boskalis Nederland in handling requirements are dominant in causing failure costs?*

VI.I Units of analysis

Units of analysis are the elements on which the focus will lie during the embedded case studies. These units of analysis are related to the fundamental problem of defining what the case is (Yin, 2003, p. 22). The definition of this unit of analysis (and therefore of the case) is related to the way the research questions are defined (Yin, 2003, p. 23). Concluding, the assumption that the unit of analysis for these embedded case study is:

> Unit of analysis:
> *Clients' requirements and the demonstrable fulfillment of these requirements*

VI.II Data collection plan

This paragraph describes the plan for the collection of data in the embedded case studies. According to Verschuren and Doorewaard, information can be extracted from a literature study, surveys, in-depth interviews and other documentation (Verschuren & Doorewaard, 2010, p. 157). This paragraph will regard the role of the sources used for this research.

In-depth interviews

The in-depth interviews will be of utmost importance for the connection of failure costs to certain proceedings. Furthermore the interviews will help in determining the origin of certain flaws. Human handlings are difficult to extract from documents, interviews will help in exposing this human influence on the process.

The results of these interviews will help validating and evaluating the conclusions drawn from the embedded case studies. The in-depth interviews will contribute to answering question 2 and 3. These interviews are of great importance to the outcome of the research and provide the main data for the report.

The in depth interviews will be conducted with one person at a time and minutes will be written of all the interviews. These minutes will be verified with the interviewee in order to make sure that there is no room for erroneous interpretation of the interviews. The interviews to be held are the following:

Case 1	**Date**
Systems engineer	January 5, 2016
Project leader	November 11, 2015
Project leader	January 19, 2016
Technical manager	September 25, 2015
Designer	January 19, 2016

Case 2	**Date**
Systems engineer	January 12, 2016
Systems engineer	January 26, 2016
Project leader	November 12, 2015
Project leader	January 26, 2016
Process manager	January 12, 2016
Executor	January 26, 2016
Project manager	January 26, 2016
Planner	January 26, 2016
Contract manager	January 20, 2016

Case 3	**Date**
Quality manager	January 11, 2016
Process manager	January 18, 2016
Systems engineer	November 18, 2015
Systems engineer	January 27, 2016
Project leader	November 18, 2015

Purchase management	January 18, 2016

Case 4	Date
Process manager	January 6, 2016
Project leader	November 19, 2015
Project leader	December 14, 2015
Designer	December 10, 2015
Head execution	December 14, 2015

Case 5	Date
Systems engineer	January 15, 2016
Systems engineer	December 2, 2015
Process manager	January 15, 2016
Project manager	January 15, 2016
Project leader	November 11, 2015
Project manager	November 11, 2015
Planner	January 15, 2016

Table 20 – Interviews per case

Other documentation

Other documentation entails minutes, current state reports or tables and figures which contribute to the research. Case studies are of major importance for this research since they help in answering questions 2, and 3. The following table identifies specific documents to be reviewed.

Documents
1. Contract
2. List of requirements
3. Requirements tree
4. Verification plans
5. Verification report
6. Examination plans
7. Examination report
8. SHE-Q processes
9. Test- and audit report intern & extern
10. Acceptation reports
11. Project management plan
12. Completion file
13. Lessons learned
14. Progress report

Table 21 – Analyzed documents

The focus in the analysis of the documentation will be on the units of analysis. Not all documents will be used for all cases. The documents are merely used as a substantiation of the interpretation of the results from the interviews. Access to these documents will be gained via the project leaders.

VI.II Screening of cases

The screening of cases will be done based on the principles summed up in the following table.

Principles	
1.	The project should contribute to a pluralist, representative set of complementary projects
2.	The project should be multidisciplinary
3.	The project has to be based on an integrated contract
4.	The project should be of sufficient size (physical/financial)
5.	The project should be at least in the realization phase

Table 22 – The principles for screening cases

Appendix II – Explanation of figures

This chapter elaborates on the standard process according to Boskalis Nederland as described in paragraph 4.1.3.

Figure 6 – The visualization of the construction process according to Boskalis Nederland

> *The image describes the process from requirement specification to completion of a project according to Boskalis Nederland visualized with an IDEFØ modeling technique which is described in paragraph 4.1.2. Both the preparation for the tender (box 1) and the realization of the project (box 2) include handling with requirements, so both processes are highlighted.*
>
> *The input for the process is the tender documents from the client. Based on these documents, the contractor prepares the tender (box 1) for which the director of projects, project director, project leader, safety, health, environment and quality (SHE-Q) manager, process manager, design leader and purchase manager are responsible. Via defining a strategy, organizing the project, defining a solution and evaluating and enhancing, the documents needed for the bid of tender phase are completed. The organization of the process and the definition of a solution both are controls which handle requirements, which is visualized by highlighting them.*
>
> *When the project is awarded, all these documents, together with the reaction from the client on these documents, are input for the realization phase (box 2). In this phase, the director of projects, project director, project leader, safety, health, environment and quality (SHE-Q) manager, process manager, design leader, purchase manager and environment manager are responsible. Via defining a strategy, organization of the project, the defining of the solution and preparing work, execution, registration and inspection an evaluation and enhancement, the project is finished resulting in a verification note, a delivery file and other documents which are requested by the client. Organization of the project, definition of a solution and preparation of the word and registration and inspection are controls which handle requirements in the processes.*

Figure 7 – The visualization of the tender process according to Boskalis Nederland

> *The image shows the sequence of the steps taken in the tender the process from requirement specification to bid according to Boskalis Nederland visualized with an IDEFØ modeling technique. The organization of the project (box 1.2) and the definition of a solution (box 1.3) are processes which include handling with requirements.*
>
> *The tender documents are the first input for the process. The director of projects and safety, health, environment and quality (SHE-Q) manager are then responsible for organization management, organization of the project management system (PMS) and management of the scope in order to define the strategy for the project (box 1.1). The result of this process is a tender plan which is input for the organization of the project.*
>
> *The organization of the project (box 1.2) is the responsibility of the project director and the process manager and is executed via document management, systems engineering and ICT management. The result of this phase is a document management plan, an ICT request, a project portal, and a systems engineering tool which are input for the phase in which a solution is formed. Systems engineering is a control which handles requirements.*
>
> *The phase in which the solution is formed (box 1.3) is the responsibility of the director of projects, the project director, the projects leader, the design leader and the purchase manager. They have to come up with a solution via the design process, a qualitative part of the bid, calculation, chance and risk management, requirement*

analysis, interface management, cables and pipelines, purchase management, permit management, stakeholder management, safety management and integral safety. The design process and requirement analysis are controls which handle requirements. The result of this process is an activity tree, a cables and pipelines register, a chance and risk budget, a chance and risk dossier, an environment analysis, an interface register, a purchase plan, a registration document, a transfer note and a verification report which are input for the evaluation and enhancement process. Also, the documents are input for the realization phase when the bid is sufficient to win the tender.

The evaluation and enhancement process (box 1.4) is the responsibility of the director of projects and results in lessons learned via an evaluation.

Figure 8 – The visualization of the process according to Boskalis Nederland

The image shows the sequence of the steps taken in the realization process from bid to completion of the project according to Boskalis Nederland visualized with an IDEFØ modeling technique. The organization of the project (box 2.2), the definition of a solution and preparation of the works (box 2.3) and the registration and inspection of the project (box 2.5) are processes which include handling with requirements.

The reaction of the client on the bind from the tender, together with the activity tree, a cables and pipelines register, a chance and risk budget, a chance and risk dossier, an environment analysis, an interface register, a purchase plan, a registration document, a transfer note and a verification report which are the result of the tender phase are the input for the definition of the strategy process (box 2.1). The director of projects project director and safety, health, environment and quality (SHE-Q) manager are the responsible employees for the production of a basic agreement, procuration and authorization scheme, project management plan, project quality plan and a work budget which are acquired as a result of the application of organization management, a decision-making framework, an organization of the project management system (PMS), a definition of the budget, and scope management. The produced documents are input for the organization of the project.

The organization of the project (box 2.2) is a process which produces a chance and risk budget, a chance and risk dossier, a document management plan, an environment analysis, an ICT request, a project portal, a stakeholder register and a systems engineering tool which are input for the solution definition and work preparation. The project director and process manager apply document management, chance and risk management, systems engineering, ICT management and stakeholder management as controls. Systems engineering is a control which handles requirements.

The definition of a solution and preparation of the work (box 2.3) is the responsibility of the director of projects, the project director, the project leader, the design leader, the purchase manager, and the environment manager. The process results in an activity tree, an alteration request register, a cables and pipelines register, an examination plan, an execution design note, an execution dossier, an interface register, an object tree, a permit register, a planning, a purchase plan, a safety, health, and environmental plan, a trade-off matrix, a verification plan, a verification report, work inspections and work plans. The controls needed for this process are design, work preparation, planning management, decision making process, requirement analysis, interface management, cables and pipelines, purchase, management, hiring material (dry/wet), permit management, communication with third parties, contract adaptions, certification, safety management, and integral safety. Design, work preparation and requirement analysis are controls which handle requirements. The documents resulting from this phase are input for the execution phase.

The execution process (box 2.4) is the responsibility of the project director and the project leader and results in a declaration of performance, a delivery dossier, examination reports, a list of installments and a production dossier which are input for the registration and inspection process. The controls needed in this process are execution, environmental findings, fact ration and certification. Environmental findings is a control which entails proceedings with requirements.

The registration and inspection of the project (box 2.5) is the responsibility of the project director, the process manager and the environment manager and needs the controls deviations, audit process, project appreciation, determining the financial state, the verification process and complaint and compliment management. The verification control handles requirements. The results of this process, an alteration register, an audit planning for the project, a budget control report, a complaint and compliment register and a verification note are input for the last process of evaluation and enhancement.

The evaluation and enhancement process (box 2.6) is the responsibility of the director of projects and results in lessons learned via an evaluation.