

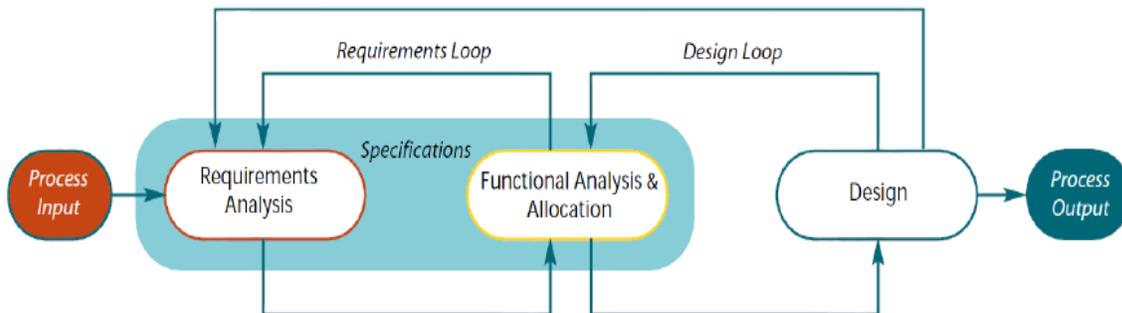
Master Thesis

Added Value of Systems Engineering in the Infrastructure Projects (Construction Industry)

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Construction Management and Engineering (CME)

January 2013



Build the **right** system and build the system **right**!

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Preface

After my Bachelor in Civil Engineering at TU Delft I got interested in managing and understanding construction projects and that was my motivation to drive continue my education in that field.

This is the final thesis for my Master education Construction Management & Engineering at TU Delft. I have been researching at RoyalHaskoningDHV on Systems Engineering within the construction projects in the last half year.

For this project I have received guidance and supervision from my graduation committee Prof. Hennes de Ridder, Dr. Sander van Nederveen and Dr. Joseph Barjis. Therefore I would like to thank them first for their academic advises and useful feedbacks.

Secondly my special gratitude towards René Kootstra who was my supervisor within the company and always helped me during my graduation and I learned a lot from his comments and expertise in practical sense as well.

Also many colleagues and correspondents inside DHV who have been supporting me or responded to my interviews which were an integral part of my practical research; I thank them all.

It was my pleasure to experience this period and definitely I learned very much about the theory and the implementation of Systems Engineering in real projects.

At the end I remind myself to thank my family and friends too for their support and encouragements.

Abdullah Hamid
January 2013

Executive Summary

ProRail introduced Systems Engineering (SE) in the Netherlands and Rijkswaterstaat (RWS) followed the trend. The process of implementing SE and Integrated Contract were supposed to increase efficiency (reducing costs and time) and gaining better results (effective) in the construction projects.

Before this, in the traditional way the client was very much involved in both the analysis and the design phase of a project. The market had less room to focus on the problem and coming up with its creative solutions for the client.

In the new way with Integrated Contracts and using SE as the main tool, RWS hoped to push the responsibility of design works and successful realization of the product, towards the market. SE originates from the telecommunication and later the aviation and manufacturing industry in the US. In those industries SE fits perfectly because there is a prototype made first and after a trial & error period the requirements are fixed and the company is ready for mass production. In the construction industry every project is unique with different stakeholders and changing environment. Also the fragmentation in the construction industry with different parties and contractual barriers in between the phases makes, it tough to implement new methods or tools from other industries.

In this report the natures of manufacturing and construction industries have been investigated and compared to one another to see where SE fits the best. Beside the theoretical part, the practical part gives answer to the main question which says:

What does the Systems Engineering approach contribute to efficiency and effectiveness in (complex) infrastructure projects?

And the sub-questions ask whether the initial goals of implementing SE are achieved, what the deficiencies of SE are and how to improve them.

Using SE is experienced and considered as an explicit way which helps the team members but also the client to trace the choices and the design objects back to the initial requirements. But also to find out why, how and when a choice was made, something was altered, verified or validated and for who (which stakeholder) were these meant.

With SE the scope of a project and the problems can be put clearer by making it structured and explicit while accessible to everyone. SE contributes to efficiency if it is applied in larger and complex projects from the start until the end. Particularly in projects that management and maintenance are also included in the contract (e.g. DBFM) which are larger projects in terms of time and costs.

Not all the initial goals of applying SE in the construction project have been achieved so far. The process still needs to be matured and for that goal, more time and experience and understading are needed.

The client expects that the solution makers would convince him and justify their designs with underpinned arguments and not only by intuitive decisions.

Implementation of SE needs improvements too. Right now, not all requirements from the analysis phase are linked to each stakeholder and the reasons behind their demands and wishes are not explicit. Also stakeholders should be more involved and their requirements should be

better investigated (why do they have such a demand/wish?).

Risks analyses are usually made for the sake of integrity while these must be used integrally and throughout the entire project.

Currently trade-offs are not performed exactly the way it is expected by SE theory and now it is only done implicitly by expert judgments.

The connection between requirements and the corresponding stakeholders is not explicit in most projects. The reason and the goal of requirements should be made crystal clear to see if they make sense and what other alternatives exist for those requirements, especially when the requirements have contradiction with one another or formulated in an abstract way.

Standardization in some aspects of trade-offs is better. Now, it is difficult to give unbiased scores and objective weight to the criteria. Quality Function Deployment (QFD) methodology can form an added value to SE when composing the requirements and evaluating these.

Analytic Hierarchy Process (AHP) can help developing unbiased weights for each criterion during trade-offs.

Interfaces still need to be managed better in the sense of making the interface requirements explicit and known to all team members from different disciplines. Also if alterations are requested by the client, flexibility is preferred and SE should allow that. Because everything is explicit and traceable the consequences of such a change can be seen quicker and this can be shown to the client immediately.

In practice, SE still needs to mature within the construction industry and better understood by both designers and by the project managers/leaders. It needs to become a habit and fit in within organizations to the extent that they know when and how and to which extent SE should be applied in every project.

The comparison in changing from traditional method to the new method (implementing SE) is like changing from an automatic car to a non-automatic car (with stick shift and clutch).

Although the traffic rules remain the same and attention has to be paid to the risks on the roads, the development of the habit and the mood in using the gear and clutch needs time until it becomes a regular habit. To the extent that the driver does not think anymore when he needs to change the gear because everything goes automatically and things seem very obvious and common.

The current implementation of SE is going slower than it was initially supposed to. The increase of successful projects and the familiarity with SE, by encouragement from the management, will prove in the future how SE will eventually mature and be accepted in the construction industry. It would then become a common tool to be used in all complex and large projects.

Moreover, SE does not reduce nor erase the complexity in a project but instead it makes complexity more manageable. It is not the SE itself that should be improved but the understanding and the correct application of it are the cause of successful implementation of SE.

Chapter 1. Introduction

Systems Engineering (SE) is a young approach that is used for construction projects since a decade ago in the Netherlands. It originates from the aerospace industry in the US and in the recent decades more industries, among which the civil engineering, have started to use this method for realization of the projects. SE is supposed to reduce the level of the complexity of (large) projects. Although, the processes in the construction world work differently than the aerospace industry, still SE has been implemented in many construction projects to achieve better results and bring a complex project successfully to the end.

In the aerospace industry the projects are very expensive and complex as well. The main difference is that there is a prototype made and the rest of the productions follows based on this. Therefore a lot of verification and validation sessions are necessary too since a missing element can cause big disasters with large damages and many casualties. In the construction world the projects have become complex as well with many stakeholders and interfaces. Due to this fact, SE is being used as it is expected to reduce the complexity and increase efficiency and effectiveness in the construction projects.

In the Netherlands, the implementation of SE is very young and still in development. It was first introduced by ProRail as an efficient tool to work with. Later on, other companies and contractors did the same in the 'hope' that SE really works better and makes the projects processes easier. There were no academic proofs or scientific arguments which could confirm this fact that SE is a better tool to use in the construction (mainly infrastructure projects) and still there aren't such arguments.

Rijkswaterstaat (RWS), which is the main client of many companies in the Netherlands, has already started to use SE as their working method because there they believe that SE has positive effects on efficiency. Since the government required RWS to work more and better with less people and less money (efficient), SE seemed to be the best method to achieve these expectations. Other companies like DHV followed this, both to respond and interact easier with RWS and fulfill clients' demands but also internally to work more effective and efficient and finally to sell SE as a product (courses and consultancy) to other clients or companies.

1.1 Problem Background

The development and implementation of SE (functional oriented) within the construction projects looks abstract and still unfamiliar to many. It's not exactly clear which differences (efficiency & effectiveness) SE realizes in comparison to the traditional way (solution oriented approach) in every Infrastructure project. There have been researches on what SE is and how its principles work. There's an experienced group when it comes to the practice and the implementation of SE. They seem to be pleased with SE but this is mainly based on feelings rather than clear and proven arguments. Thus, there's need for underpinned arguments which do not exist now.

This causes negative risk perception of SE for some experienced managers who have been using the traditional approach for a long time and got used to it as well as having seen the advantages/disadvantage of the previous method through decades.

Within the Infrastructure Unit of DHV it's been decided to use Systems Engineering as the new approach for the projects (€>50K). This method is meant to be used both externally (to sell it as a product) and also as a tool to implement it into the projects (functional and technical processes).

The main reason that DHV¹ has come to this decision is to increase efficiency, quality and add value to its products. It's the question whether or not SE really contributes to those promises.

Due to the fact that SE is a young concept and somehow perceived as abstract within the construction world it's not clear how to use it and when it can be applied in a project. At the same time there are no underpinned arguments to assure and to confirm whether SE truly works more efficient and effective than the traditional way.

These unknowns may cause uncertainties and lack of interest for some project members too when using SE.

There's also uncertainty whether SE is suitable and applicable for every type of project when it comes to the size (large, medium and small) of a project and its nature (water, infra, buildings etc.). Although this requires more elaborated researches on many different types of projects and would be outside the scope of this thesis.

According to a recent academic research², before the implementation of SE and SCB³, RWS did not ask the right questions nor examined them in regard to how/why implementing methods like these. The consequences are that these methods have not met the needs, do not support the way it was expected and the desired results are not achieved.

¹ DHV has merged with Royal Haskoning since July of 2012 into Royal HaskoningDHV. Though, this report was mainly composed during the research period at DHV before the merging. Therefore DHV will be mentioned in this report as the company's name.

² Gazelle van de M., *Samenwerken is vertrouwen, is loslaten, is delen en is leren*, Sep. 2011

³ **Systeemgerichte Contractbeheersing** (System-Oriented Contract Management), integrated contracts such as Design&Construct (D&C) or DBFM.

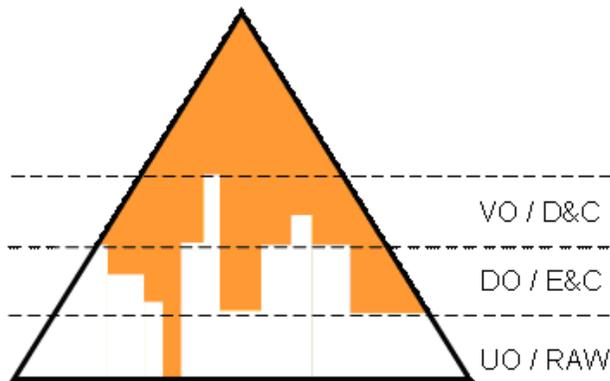


Figure 1: Different types of contracts

According to Prorail⁴ “SE is meant to prevent problems during a project and this would lead to reduction in time, money and effort. Still the high abstraction level of the system could withhold people from implementing SE in their projects.”

Figure 1 depicts different forms of contracts in the Netherlands.

Design & Construct (D&C) goes as deep as Preliminary or Concept Design (Dutch: Voorontwerp). Engineering & Construct (E&C) is another step further and, according to the agreements, it could include until the Final design (Dutch: Definitief ontwerp).

RAW is the common contract form in the Netherlands (before implementing Integrated Contracts) in which much more is specified by the client and some parts could even be done until the Implementation design (Dutch: Uitvoeringsontwerp) and those form the Tender documents which can be used for the realization phase by a contractor.

⁴Prorail, the main client responsible for the railways, is the first company in the Netherlands that started to use SE in the Infrastructure projects as a tool to reduce complexity. This company copied it from the Fokker Company (aviation industry) which was active in the aviation industry and after a few managers of the Fokker company started their jobs at ProRail and RWS, they lobbied to implement SE as the main tool inside construction projects as well since it worked very efficient and well in the aviation industry.

1.2 Problem Formulation

As mentioned before there are uncertainties and ambiguity when using SE and its added value to a project in the construction industry. There are questions about how efficient and effective it is to use SE when compared to the traditional approach without using SE (with Tender documents⁵).

Figure 2 shows the basic principle of how the traditional way (solutions oriented) works. After Client has explained his demand and wishes, an object is proposed as a solution and specifications are made. This process goes deeper and becomes more detailed. When calculations and drawings are in the Final Design (FD) stage, they are handed over to the contractor who builds according to FD.

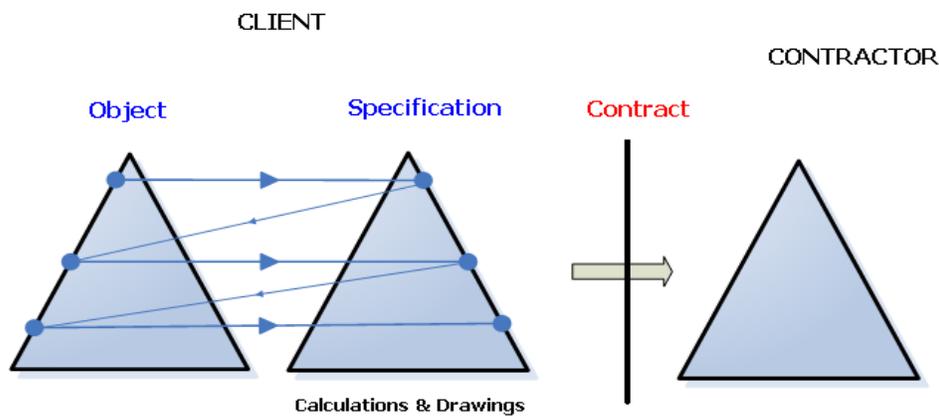


Figure 2: Traditional way without SE

In the new way (functional oriented) with Integrated Contracts, the client is supposed to give more space to the contractor. The contractor is involved in the projects at an earlier stage. The client does not make the drawings and it's the contractor's responsibility. There's a transformation phase from Specification (without drawings) to Functional Requirements. Here things can go wrong since the client makes his requirements and wishes clear but does not provide the drawings while expecting the contractor to make the drawings according to initial requirements (Figure 3).

⁵ SoW: Statement of Work or Tender Documents, Dutch: Bestek

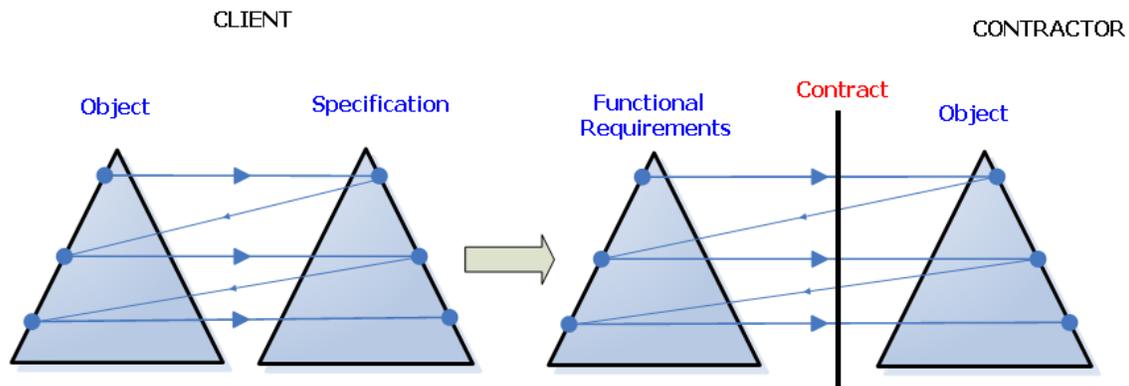


Figure 3: New method with SE and Integrated Contracts

There's need for a research to find underpinned arguments which prove that SE works as it is supposed to be or maybe it doesn't work so well in the construction world at all. After some research on the background and the history of SE a comparison between the traditional way and the new approach (SE) could clarify the main differences and similarities. After this, looking at why SE should (not) be applied on construction projects will shine light upon the suitability of SE on infrastructure projects. This will either remove or confirm these uncertainties and doubts about using SE in general.

At DHV they would like to get more insight into the state of the art when/how SE should be applied. To know when SE adds value to a project and how it does. To which extent SE should be used in a certain type of project.

It takes some time and effort when changing from the traditional way into SE method.

Therefore, various strategies can be applied to accelerate the process of transformation.

However, when the processes of SE are clarified and are made easy to apply, then using SE might not be seen as a challenge anymore. The project team can use a table/matrix which can categorize a project type (based on some criteria and the nature of the project) and as output one gets to know whether SE is the suitable method to approach a solution for this type of project or it is not useful at all.

Also in the thesis research of M. van de Gazelle it was suggested that "A systems structuring should be developed which enables a roadmap that can be applied on every Infra project, taking into account the dynamic and the project's type."

To be able to understand how SE really works and why is it developed, one should go back to the origin of it, which is the manufacturing industry (where SE has been applied successfully), and look into the processes and how they work. After understanding them, one can study SE method applied in those industries. Hereafter, the construction industry should be studied and why/how SE does (not) work in this industry as a suitable tool/method for process and design.

Hypothesis: Systems Engineering is an explicit approach which causes success in one shot⁶ and the clients gets the optimal product which he wishes to have.

The objective of this research is to look into the building processes of infrastructure projects and argue why SE does (not) work effectively and whether or not SE can be improved and to which extent it can be applied in the projects.

The main research question: What does the Systems Engineering approach⁷ contribute to efficiency and effectiveness in (complex) infrastructure projects?

Sub-questions

1. What were the initial goals of applying systems engineering in the construction industry?

(Research Method: this question can be answered through literature review, review of past projects, and interview with experts)

2. Considering the current application of systems engineering approach within the Dutch construction industry, to which extent have the initial goals of SE been achieved?

(Research Method: this question can be answered through analysis of past projects, interview with experts, case studies)

3. How can the system engineering approach be improved for application in the lifecycle of construction (infrastructure) projects?

(Research Method: interview with experts, reflective analysis, cases studies)

⁶ One shot here refers to an assumption which says SE works well at once and there's no need for trial and error in the building industry. This is in fact in contradiction to the nature of Design and Engineering where trial&error plays a major role.

⁷ SE approach as it's been described in the Handbook of Rijkswaterstaat (Dutch: Leidraad) and practiced by contractors in the Dutch construction industry.

1.3 Research Methodology

In this part the methodology of this research will be explained how the research question will be answered and what procedures need to be taken before any result and conclusions can be found.

To be able to carry out this research successfully a methodology has to be developed. This way, gaining satisfactory results and answers to the main and sub questions will go more smoothly. SE should be studied in depth by looking into previous researches and handbooks on SE.

Therefore defining the framework beforehand is needed as well.

The activities will vary from studying the theories to practical experiences in real life. Looking into construction processes and different contract forms will give a good understanding of how the building industry works. Hereafter, finding out why SE is applied there and whether it's justified to implement it in the Infra (GWW)-sector too which will be the next challenge. The following activities need to be done:

- **Literature study on the principles of SE and its application in the Construction Industry (CI) and the Manufacturing/Aviation Industry.**
- **Analyzing the processes within the Construction Industry and the traditional method**
- **Interviews with project managers/ SE engineers, how they use and experience SE in their project processes**
- **An in-depth case study in which SE was applied as the main tool**
- **Finding underpinned and rational arguments based on the aforementioned activities**

These are amongst the possibilities so far and the most suitable ways to perform this research. It's beyond the scope of this thesis to look too deep into each and every aspect (e.g. contracting, reimbursement, financial, technology, stakeholders, communications etc.) of all projects but rather an overall view is needed to find out how and to which extent SE should be used.

In other words, some literature research is needed about the construction industry (the processes and the principles) and how SE came into the Construction Industry. This, along with practical experiences from interviewees and rational arguments, make it possible to formulate underpinned evidence for why (not) using SE.

The handbooks from US Department of Defense, ProRail, BAM, RWS (Leidraad), Volker &Wessels., academic research papers about SE in different industries and previous thesis's on SE are going to be studied to understand how SE works and how it is being implemented and understood in different practices.

When a comprehensive understanding of the main issues have been developed, the uncertainties, unknowns and doubts will be formulated into questions.

Right questions need to be asked from experienced managers and SE Engineers to see what is happening in the practice and why (not) SE is considered a useful tool to use in the Infra projects. Also two in-depth case studies are going to be done to complete the practical part. In these two case studies the use of SE and the different phases of a project will be investigated.

Finally, the findings will be examined again with consultants and expert. Hereafter conclusions and recommendations can be given to both the DHV Company as well as to the academic staff (Figure 4).

1.3.1 Framework of the thesis

The focus of this research is on Infrastructure projects within the Dutch construction industry. One can look into the building processes from a specific point of view namely as a client, advising/engineering company or a contractor.

This research will be carried out from a fresh and independent viewpoint to see if using SE in general really matters and how it can be improved. Also the application of SE in construction industry, more specifically, only in the infrastructure projects is considered.

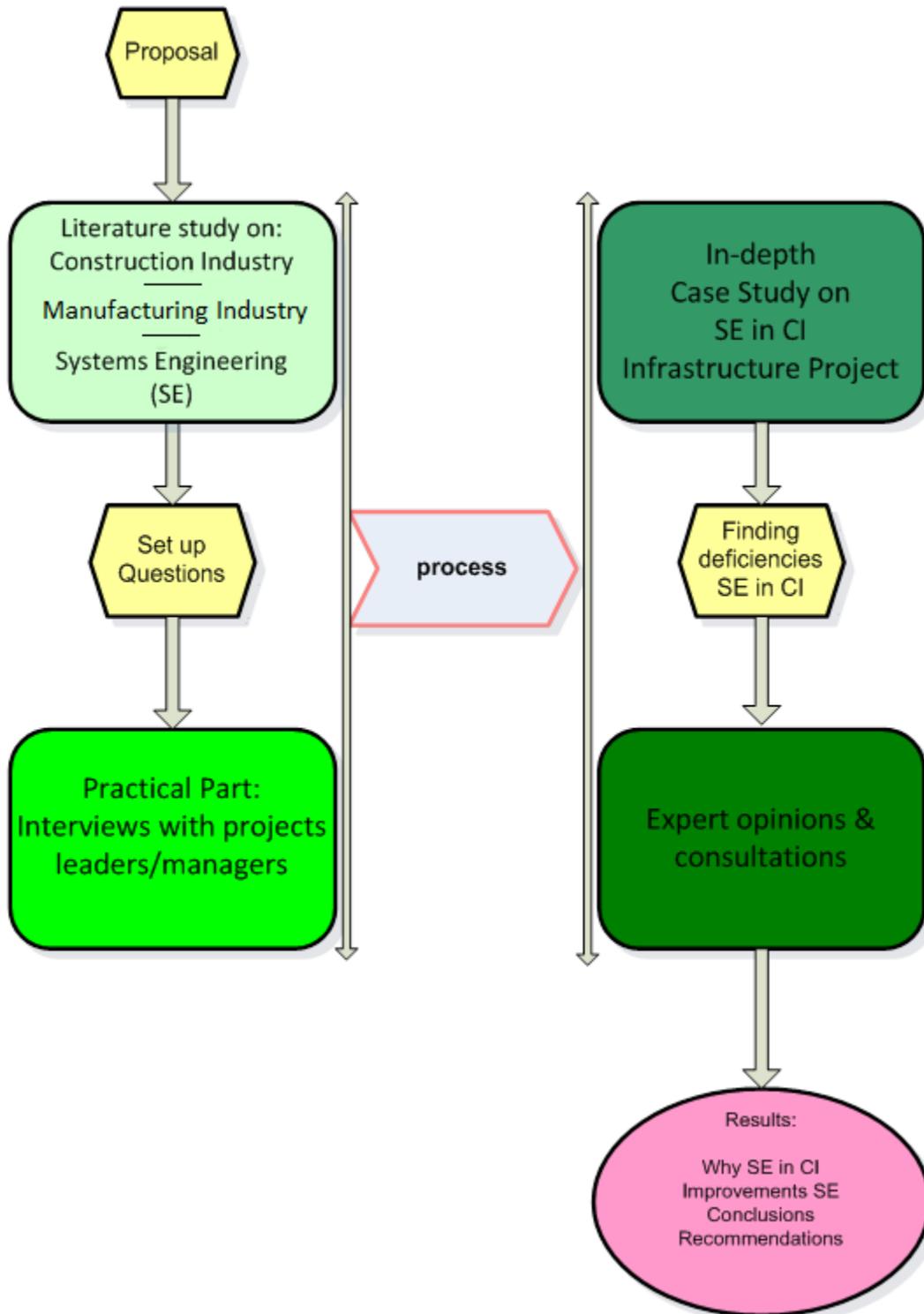


Figure 4: Research Model

Chapter 2. Systems Engineering and its Relevance

In this chapter a brief history and the theory of Systems Engineering (SE) will be investigated. This is needed to understand what SE initially was meant for and how its principles work. Here SE is considered in the broader and general sense.

There are several definitions of SE such as these:

- (1) *Any application of a combination of traditional engineering and holistic systems thinking, working with domain engineering, human sciences, management and commercial disciplines, to support the engineering of one or more systems of interest to come.*
- (2) *Interdisciplinary approach governing the total technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life. (SEBoK⁸).*
- (3) *An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Performance, Test, Manufacturing, Cost & Schedule, Training & Support, Disposal.*

Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs (INCOSE⁹ 2010).

2.1 Systems Engineering Overview

Since World War II the attention for SE has grown due to the increase of complexity in design problems and in successful realization of projects in general.

The origin of SE starts from the telecommunication industry in US and its development occurred mainly in the defence and aviation industries. In such industries projects run over time and over budget, they are large and challenging and there's need for a better approach.

That is why SE has been developed which was considered as a method that structures the process and reduces the complexity of projects. This is needed to gain more effectiveness in

⁸ Guide to the Systems Engineering Body of Knowledge (SEBoK) v. 0.5

⁹ The International Council on Systems Engineering (INCOSE) is a not-for-profit membership organization founded to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems.

projects and meeting client's demands and wishes better which should lead to successful projects as well. In other words, SE is a structured methodology for successful implementing and managing of generally complex and large scale projects. Due to this fact, other industries (mainly automotive) started to use SE in the projects. One of these industries is that of constructions in which the projects are becoming larger and more complex.

SE is sometime not understood well in projects and not implemented correctly as it should be in practice.

This is caused because the nature of industries differ; for example automotive (with prototypes) versus construction industry (unique projects) and not so many managers/engineers are familiar and experiences with SE in the construction industry.

2.2 Systems Engineering Scope

SE concerns the entire project life cycle and can be summarized as follows:

- The structured specification of a requirement
- The structured design of a suitable solution to the requirement
- Use of the proper approach to produce this solution
- Use of the proper approach to manage the produced solution
- Use of the proper verification and validation approach
- Use of a controlled approach to manage the total system during its entire life cycle

It is a way of achieving successful results while involving (all) stakeholders from the initial phase of a project. Designing with functional, physical, and operational performance requirements in the intended use environment over the planned life of the systems, is another reason for using SE.

The primary benefit of doing systems engineering is that it will reduce the risk of schedule and cost overruns and will provide a system of higher integrity. Other benefits include:

1. Better system documentation
2. Higher level of stakeholder participation
3. System functionality that meets stakeholders' expectation
4. Potential for shorter project cycles
5. Systems that can evolve with a minimum of redesign and cost
6. Higher level of system reuse
7. More predictable outcomes from projects

The key principles of systems engineering are:

- View the system from the stakeholder points of view [walk in the shoes of the system's owner and stakeholders]. Key processes include needs assessment, elicitation, Concept of Operations, and stakeholder involvement.
- Start at the finish line defines the output of the system and the way the system is going to operate. Key processes include Concept of Operations and Validation Plan.
- Address risks as early as possible where the cost impacts are lowest. Key processes include risk management, requirements, and stakeholders' involvement.

- Push technology choices to the last possible moment. Define *what* is to be done before defining *how* it is to be done [form follows function].
- Focus on interfaces of the system during the definition of the system. Defining clear and standard interfaces and managing them through the development will ease the integration of the individual elements of the system.
- Understand the organization of the system's owner, stakeholders, and development team (Manual Integration and Orientation CME, 3TU, 2011).

2.3 Systems Engineering Methods

A comparable method to SE is Quality Function Deployment (QFD) which is being used in automotive and manufacturing industries. It is the systematic translation of the "voice of the customer" to actions of the supplier required to meet the customers' desires, based on a matrix comparing what the customer wants to how the supplier plans to provide it. (Anthony Coppola, QFD in Selected Topics in Assurance Related Technologies [START], Volume 4, Number 1).

In other words, it's a method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process as described by Dr. Yoji Akao, who originally developed QFD in Japan in 1966, when the author combined his work in quality assurance and quality control points with function deployment used in Value Engineering¹⁰. (Wikipedia, September 2012)

Similar methodology is supposed to be performed in the construction industry as well. Translating client's demands and wished into technical requirements while taking risks and interfaces requirements into account as well.

Although in the traditional way always a list of demands is there before designing but with using SE, one is expected to make the choices unbiased while explicit and traceable.

QFD is also applied in a wide variety of services, consumer products, military needs and emerging technology products. The technique is also used to identify and document competitive marketing strategies and tactics (Figure 5).

House of Quality appeared in 1972 in the design of an oil tanker by Mitsubishi Heavy Industries. Akao has reiterated numerous times that a House of Quality is not QFD, it is just an example of one tool (Wikipedia, April 2012).

¹⁰ **Value engineering** (VE) is a systematic method to improve the "value" of goods or products and services by using an examination of function. Value, as defined, is the ratio of function to cost. Value can therefore be increased by either improving the function or reducing the cost. It is a primary tenet of value engineering that basic functions be preserved and not be reduced as a consequence of pursuing value improvements. Value engineering is often done by systematically following a multi-stage job plan. Larry Miles' original system was a six-step procedure which he called the "value analysis job plan." Others have varied the job plan to fit their constraints. Depending on the application, there may be four, five, six, or more stages. One modern version has the following eight steps: Preparation, Information, Analysis, Creation, Evaluation, Development, Presentation, Follow-up. (Wikipedia, visited on March 2012)

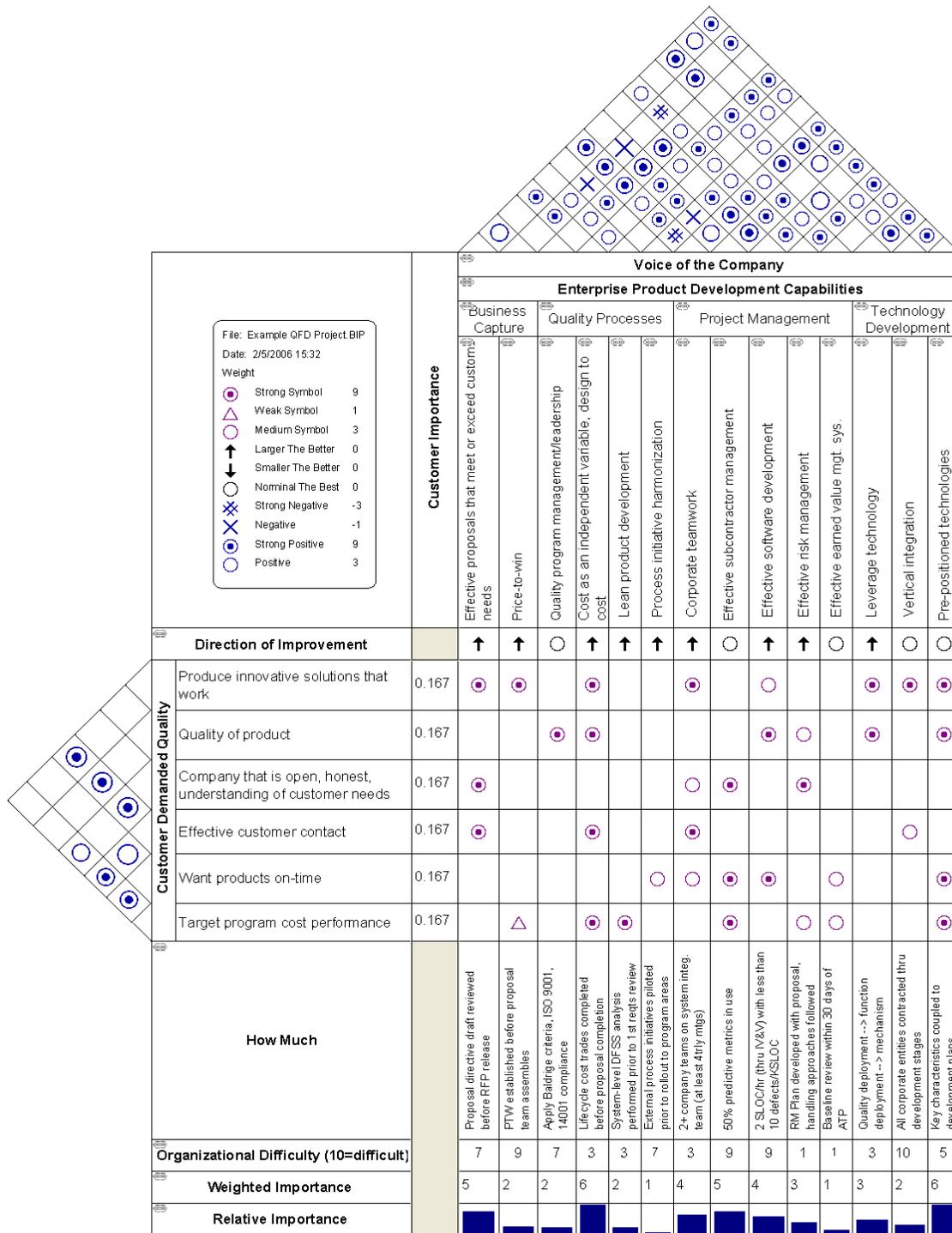


Figure 5: House of Quality diagram (source: Wikipedia March 2012, http://en.wikipedia.org/wiki/House_of_Quality)

2.3.1 House of Quality

House of Quality is a diagram (Figure 6) resembling a house, used for defining the relationship between customer desires and the firm/product capabilities. It is a part of the Quality Function Deployment (QFD) and it utilizes a planning matrix to relate what the customer wants to how a firm (that produces the products) is going to meet those wants.

It looks like a House with a "correlation matrix" as its roof, customer wants versus product features as the main part, competitor evaluation as the porch etc. (Figure 6). It is based on "the belief that products should be designed to reflect customers' desires and tastes". It also is reported to increase cross functional integration within organizations using it, especially between marketing, engineering and manufacturing.

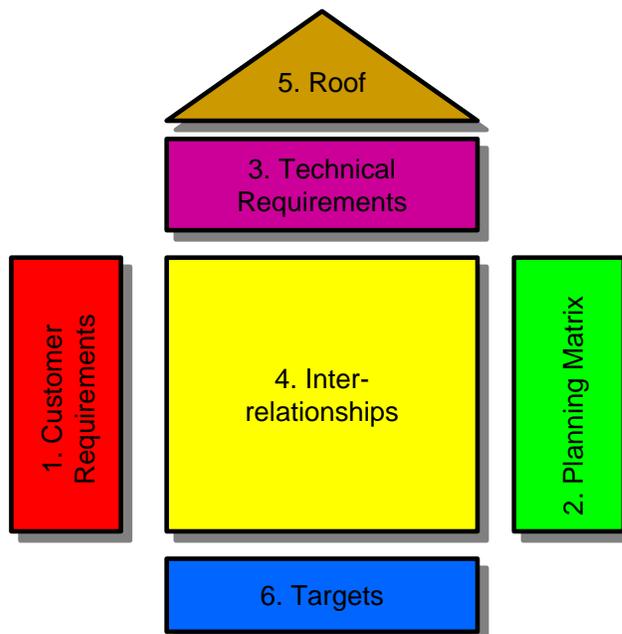


Figure 6: House of Quality elements (source: slides QFD for Software Requirements Management, Davis, G., et. al., http://www.slideshare.net/guy_davis/quality-function-deployment)

The basic structure is a table with "Whats" as the labels on the left and "Hows" across the top. The roof is a diagonal matrix of "Hows vs. Hows" and the body of the house is a matrix of "Whats vs. Hows". Both of these matrices are filled with indicators of whether the interaction of the specific item is a strong positive, a strong negative, or somewhere in between.

Additional annexes on the right side and bottom hold the "Whys" (market research, etc.) and the "How Muches".

Rankings based on the Whys and the correlations can be used to calculate priorities for the Hows. House of Quality analysis can also be cascaded, with "Hows" from one level becoming the "Whats" of a lower level; as these progresses the decisions get closer to the engineering/manufacturing details. (Wikipedia, visited on March 2012).

2.3.2 Unbiased Weights in the Trade-offs

As for the trade-off itself and creating unbiased criteria and their weights, the Analytic Hierarchy Process (AHP) is an additional option to be used in the construction industry.

This is a pair-wise analysis in which a list of criteria is made and both the future users/customers and the experts can choose their preference. The criteria they think are more important than the others get higher grades and thus a heavier weight for in the trade-offs.

An example of this has been shown in Chapter 7.

Conclusion

SE as a method was started before World War II in the telecommunication industry in the US and later it was used in the defense projects to decrease complexity in the project. Other industries such as aviation started to adapt this method for increasing efficiency as well. SE can be defined as an interdisciplinary approach and means to enable the realization of successful systems while focusing on defining customer needs and required functionality early in the development cycle.

SE concerns the entire life cycle and structures the whole projects by making each step explicit and documented and the demands and wishes of all stakeholders along with the risks are considered when designing solutions. The trade-offs and choices should be made unbiased and they need to be traceable as well.

Chapter 3. Global Practices of Systems Engineering

In this chapter the developments of Systems Engineering will be considered in the global practices. Since it's been used and development in the USA on large scale and in many projects, the US Department of Defense has been taken in the scope of this report as well. SE was used in different projects and in particular aviation and defense projects.

3.1 Systems Engineering by US Department of Defense

The US Department of Defense (DoD) is one of the first organizations which uses and has contributed to the development of SE, particularly in the aerospace and military disciplines. The handbooks published by UD DoD are used worldwide as an example. To find out how SE was developed and what the philosophy behind SE is, in this chapter an elaboration is given on that.

According to the US Department of Defense: "Systems Engineering is an interdisciplinary engineering management process that evolves and verifies an integrated, life-cycle balanced set of system solutions that satisfy customer needs."

DoD explains SE process as: '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, generate information for decision makers, and provide 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'.

Thus the process will be repeated until a design has been developed that is ready for realization. The DoD uses three types of management and they are technical, business and contract management. Within technical management SE is used for acquisition, development and operation of military systems. Figure 7 depicts how systems engineering is an integration of *three major activities*.

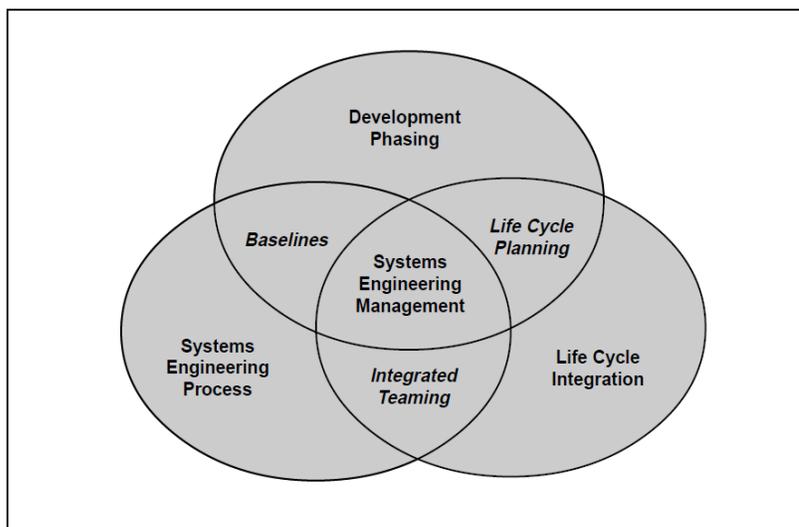


Figure 7: Three major activities by DoD (source: *Systems Engineering Fundamentals, Handbook of US DoD, January 2001, page 4*)

The characteristic activities, present in the systems engineering process of the Department of defense, are: the requirements analysis, the functional analysis and allocation and the design synthesis. Figure 8 shows how these different activities relate to each other and how they can influence each other, by the requirements loop, the design loop and verification.

Systems Analysis and Control, also presented in Figure 8, is present to balance the three systems engineering activities and to manage and control the process on general aspects such as quality, time and costs.

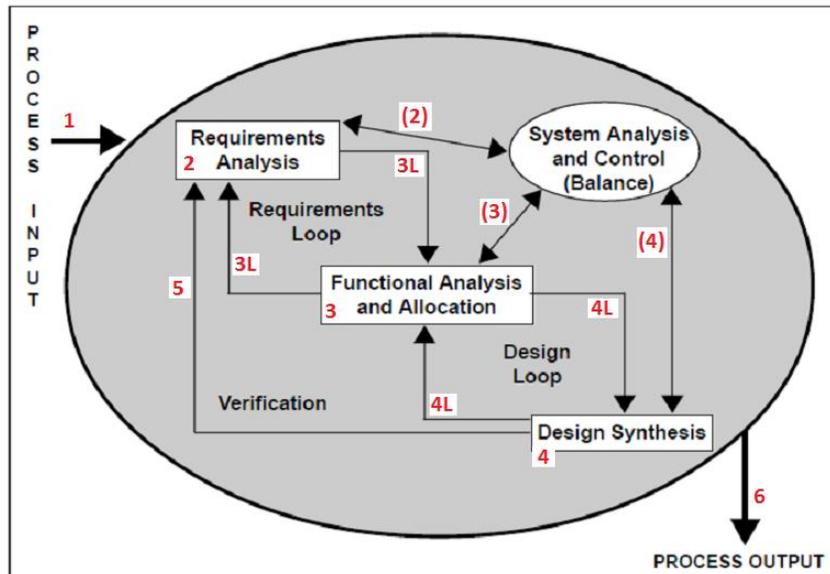


Figure 8: SE phases in the model of DoD (source: *Systems Engineering Fundamentals, Handbook of US DoD, January 2001, page 6*)

3.2 Department of Defense Process Model

Input 1

To start the SE process, input is required. This can be available in diverse forms and amounts; this partly depends on the level of detail at which the process takes place.

One needs client's wishes, requirements and his objectives. Defining the solution space could also be considered as an input. Here external factors like technology, regulations and external interfaces limit the borders of a solution space. This space defines how viable a project is during its lifecycle. Input is necessary to give direction to the design process. These aspects result in missions, measures of effectiveness, environments and project constraints that in the end of the process will lead to adequate output.

Requirements analysis 2

The input is being analyzed in this process. The requirements of the client form the basis of a more detailed system specification. Here the requirements are well and clearly defined. All the demands and wishes of the client in regard to the end product are transformed in the requirements. Also the constraints which determine the limits and the boundaries of the systems are put in the specifications. The possible trade-offs are also discussed in this stage as well as the project promises.

Functional Analysis and Allocation 3

The output of the previous step (requirements analysis) is the input for this step. Here the requirements get more detailed and better defined but also tasks are allocated to them. The output of this step should clarify the end product very well in accordance with its requirements. Also hazards that may occur are being clear and determined here. So the functions are allocated and this allocation happens based on detailed requirements analysis and each of these functions are known which priority they have.

Requirements Loop 3L

The loop step is seen very often in the systems engineering model. By looking back one can check and see if the current functions, that have been defined in step 3, are really in accordance to client's requirements and wishes or not. Since SE is an iterative process and the systems is being decomposed into subsystems, there should also be looping steps within a step to make sure that everything is going well and according to plan e.g. client's demands.

Design Synthesis 4

In this step the team is supposed to come with a design and possible alternatives. Of course all of these should be based on the requirements from the previous steps. That's why the input for this step is called the functional architecture which is in fact the detailed description of the requirements and the constraints. As for the output of this step the term physical architecture is used which is the physical designs like drawings, calculations etc.

Design Loop 4L

Here too a loop is necessary to look back and see if everything has happened according to the right requirements and whether the functions can perform well as it was described in the previous step, Functional Analysis and Allocation.

Verification 5

After the developing phase once again the final design is being tested against the initial requirements of the client. Are all his demands and wishes met? This is needed to make sure that the outcome is not something else than the wished and demands of the client.

Process Output 6

Finally the output of the development phase is there. If more details are needed the process is simply repeated over and over. When a project starts less details are available than at the end. The output of the systems engineering process depends upon the level of development at which design activities have taken place. It will at least include a decision database, a system or configuration architecture of the item and baselines (Handbook Systems Engineering of US DoD, 2001). The decision database documents and substantiates the decisions made configuration of the solution. The baselines formally describe the solution by using specifications of the different elements required for the solution.

System Analysis and Control (Balance)

Unlike the loops that control the previous requirements, System Analysis and Control is a supporting step that is used to measure the entire progress. At the same time in this part evaluation and selection of alternatives along with documentation of data and decision are being done. Due to the importance of transparency in SE this step is needed to put everything like the measurements, alternatives, decisions that were taken etc. on paper. When it is necessary, things can be looked into afterwards for example to see why a certain alternative was chosen. Also this step helps to see if the choice of alternatives and decisions are made based on the functional and technical requirements while taking the risks into account. At the same time the schedule of the project is being controlled. Systems engineering is used by the Department of Defense to make sure that needs and requirements are transformed into an integrated multidisciplinary system. It is used to manage risks and improve the system throughout its life cycle. Lastly, by using the SE model the DoD hopes to identify security, vulnerabilities and diminish protection risks and improve overall safety (Handbook of US Department of Defense, 2001).

Conclusion

US DoD is the major developer of SE due to their need of efficiency and quality product in their large scale and complex projects. The Handbook that was made by UD DoD is a comprehensive guideline for understanding SE in large engineering projects. The focus is on designing in phases while verifying and validating the results after each phase against the initial requirements. If these guidelines are going to be used in other industries like in the construction project, then one should know the nature and the culture in the construction industry as well and compare this to manufacturing/aviation industry before using SE. In the next chapter these two industries are going to be investigated further.

Chapter 4. Construction and Manufacturing Industries

SE started in the USA and developed in aviation and defense projects and later it came from those manufacturing industries into construction industry in the Netherlands. In this chapter, first the nature of manufacturing industry will be investigated.

Then the construction industry will be looked into which finally makes it possible to make a comparison between the two industries to see how SE can fit into each one of them. Hereafter the report continues towards the construction industry in particular.

4.1 Manufacturing Industry

The manufacturing/automotive industry is very broad and the focus is mainly on the mass production of good quality products for various clients (Figure 9: Innovation in Megaprojects (source: Systems Integration at London Heathrow Terminal 5, Andrew Davies et al., 2009. 104 California Management Review Vol. 51, No. 2 Winter 2009 cmr.berekeleyu.edu).

As Barrie and Paulson (1992) have put it: "Manufacturing is inversely characterized by mass production, stock production, and factory production."

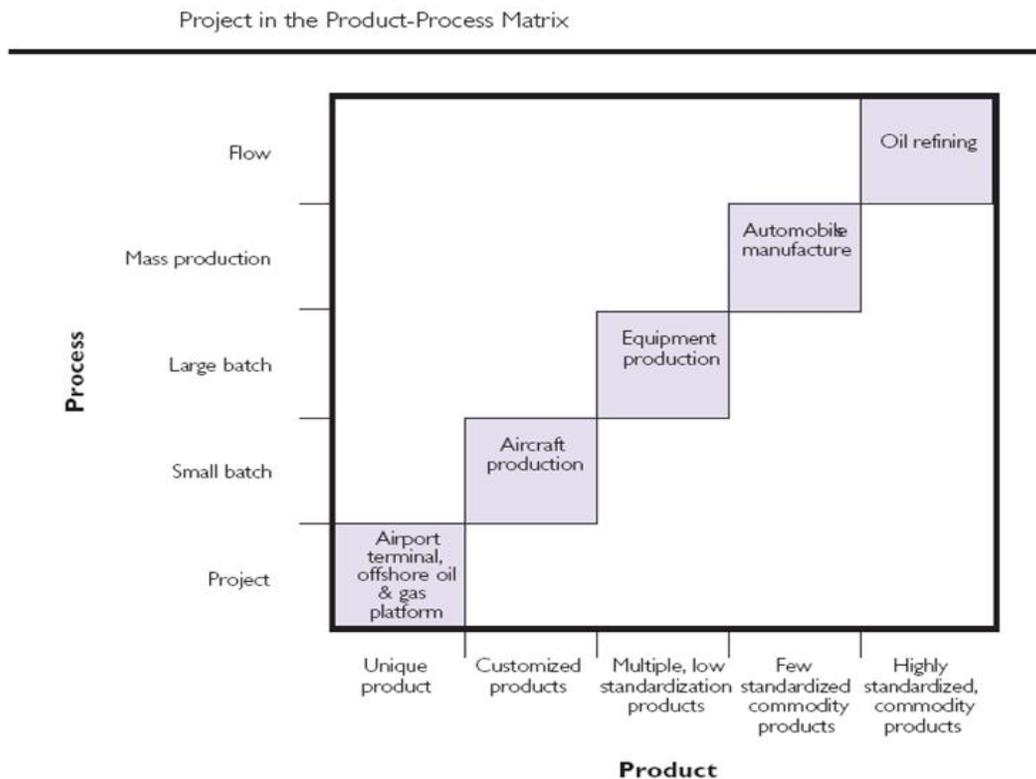


Figure 9: Innovation in Megaprojects (source: Systems Integration at London Heathrow Terminal 5, Andrew Davies et al., 2009. 104 California Management Review Vol. 51, No. 2 Winter 2009 cmr.berekeleyu.edu)

Manufacturing industry differs from the construction industry in the fact that there's usually a prototype and after a trial & error period all the requirements are known and fixed. The next step is the (mass) production of the products. This happens for instance in the car manufacturing and electronic devices.

In the defense projects the processes seem similar, although, there is less mass production as it is in the car manufacturing.

The defense projects vary from producing small military equipment and weaponry to aircrafts and rockets which need to be designed and meet all the requirements without errors. This is because a small error could be fatal and cause huge damages in such projects.

Hence, the verification & validation loops are necessary and inevitable in manufacturing projects.

Riley and Clare-Brown have found that different manufacturing industries show similar cultures (2001). Therefore it is assumed that the processes in the aforementioned industries and branches are similar when it comes to producing products and they differ with construction industry in which more separated parties and contracts in between them are involved.

Conclusion

In the manufacturing the project are made by the company and sold to the client on the market. It means that the clients have usually less influence on the design phase. They can only choose the product they like when it's on the market.

The projects are bottom-up¹¹ because the main requirements are fixed and the components are known and they are brought together to make a whole system.

4.2 Construction Industry

Construction industry seems to be divided in many different disciplines from buildings, water construction, water management to transportation and traffic, road and railways.

However, David J. Delgado-Hernandez et. al. (2005) mention two main type of construction projects. "According to the Construction Statistics Annual (Department of Trade and Industry, 2003b), there are two main types of construction project: building and civil engineering."

Austen and Neale (1984) highlighted the difference between the two types of projects by stating that buildings were structures in which people would work or live while civil engineering works were related to manipulating the natural environment to offer an 'infrastructure', e.g. roads, airports and bridges.

Traditionally, a construction project has comprised several steps called the construction process, a schematic of which is shown in Figure 10 and is based on internationally accepted practice (Austen and Neale, 1984).

¹¹ A bottom-up approach is the piecing together of systems to give rise to grander systems, thus making the original systems sub-systems of the emergent system (Wikipedia, September 2012)

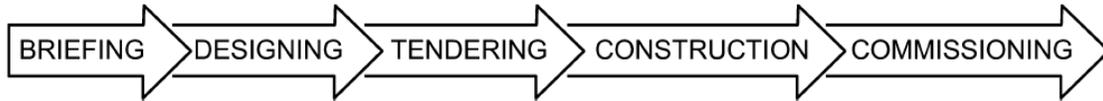


Figure 10: Stages of a construction project (source: Austen and Neale, 1984, http://fi.uaemex.mx/david.delgado/files/9_ITinUK_CME.pdf, Page 2)

The clearly defined stages vary from project to project depending on the contractual arrangements.

Harris and McCaffer (1995) summarized various forms such as cost reimbursable contracts, two stage tendering, serial contracts and management design.

More recently, the American Institute of Architects (AIA, 2004) defined three of the most common procurement approaches that are being used today within the industry: design-bid-build, design-build and construction management at risk.

While the first is normally recognized as the 'traditional' delivery method in which two separate contracts are typical, owner-designer and owner-builder, the second, makes use of only one contract, designer-builder. In terms of the last method, a construction manager takes the risk of building a project and an architect is hired under a separate contract.

Again, the stages depicted in Figure 10 may vary depending on the contractual arrangements adopted for the particular project; however, in this piece of research the traditional approach will be used. As can be seen there are five stages present in construction projects, briefing, designing, tendering, construction and commissioning (David J. Delgado-Hernandez and Elaine M. Aspinwall, 2005).

In the briefing phase, the customer (who could be either the client or the end user) specifies the project purpose and the likely budget. Consequently, architects, engineers and the design team are able to interpret the customer's needs and requirements and supply their cost estimates.

The project brief is finalized at the designing stage in which the layout, design, methods of construction and estimated costs are detailed. The customer and the appropriate authorities approve the project once they are convinced that it satisfies the requirements. All the necessary production information – such as working drawings, schedules, bills of quantities, time scales and specifications – are prepared ready for the tendering phase. The main purpose at this stage is to appoint a building contractor (it could be one or more), who will carry out the site construction work. It is not uncommon for the cheapest bid to win the contract. Since the final decision is based on price, quality and contingency costs are ignored leading to problems at the end of the construction process (Chen and Liew, 2003).

The construction phase is concerned with building the structure within the approved time, budget and quality limits. Suitable supervision of the work is organized to certify conformance to both quality standards and legal requirements.

Finally, at the commissioning stage the building or the civil engineering work is inspected to ensure that it conforms to the contractual and legal requirements and that all the facilities work adequately. Certificates of compliance for the actual construction along with any necessary operating instructions are given to the customer. It is at this stage that any final amendments such as repairs of leaks (identified after the construction stage) are carried out (David J.

Delgado-Hernandez and Elaine M. Aspinwall 2005).

Conclusion of construction industry

In the construction industry the client starts with an initiation or briefing and presenting his demands and wishes. After the analysis phase the designing phase can start and eventually the realization and maintenance follow and based on the type of the contract each phase can be done by one or more parties. A typical nature of this industry is that there are several contractual barriers between the involved parties due to these fragmented phases.

4.3 Comparison between the Manufacturing and Construction Industries

Now the main phases and the nature of the construction industry are known, the next step is to compare this with the manufacturing industry. This will shed more light upon understanding why and how SE is (not) a suitable tool to be used in each of these industries.

There have been many researches on the differences and similarities between the construction industry and the manufacturing industry.

It is possible to trace similar stages of development in an area similar to the manufacturing new product development (NPD), in the construction industry. This area deals with the development of solutions (usually the building type) which aim to satisfy client requirements. However, depending on the type of contract or procurement strategy between the customer and the main contractor, NPD usually refers to: design and build, build to own, develop and construct, design - build - finance - operate, build - own - operate etc. or more generically design and construction. (Kagioglou *et al.*, 1998).

As Kagioglou *et al.* mention, manufacturing industry focuses more on the client requirements and that industry is much more solution oriented. They remark that new approaches like Design & Construct would be implemented in the construction industry as well to reach those aforementioned aims.

In the lack of an established definition of a *process*, the construction industry was and still is trying to utilize 'procurement systems' rather than looking at the overall process as a whole entity (Kagioglou *et al.*, 1998).

This is because the building industry is pretty fragmented and usually the different parties are competitors of each other. The construction process cannot be seen easily as a whole since there are interfaces and handovers in between.

According to Kagioglou *et al.* a number of lessons can be learned from the manufacturing sector with regards to the implementation and practical use of a 'process view' within the construction industry. A number of similarities can be found between the two industries with regards to the activities used for developing new products. For example they include:

- The start of a project can be initiated internally or by direct and/or indirect contact with the customers.
- The development of the product requires the participation of a number of specialists and functions such as: designers, surveyors, marketing, stress analysts etc.

- The successful construction or manufacturing of a building or product can only be achieved if all external (suppliers and consultants) and internal resources are utilized and coordinated effectively (It's not been explained how that should happen).
- The building or product is handed over to the client and provisions are made for future support (e.g. a guarantee on a computer or the maintenance contract or a road/railway).

However there are a number of distinct differences, the most important of which is that in the manufacturing industry all NPD activities are coordinated, managed and controlled based on a common framework which is the NPD process.

The construction industry mainly, uses ad-hoc¹² methods for achieving the latter and therefore reducing repeatability of process execution, resulting in the same mistakes occurring time after time.

This shift into the establishment of a consistent process for the construction industry requires a new way of thinking entailing a change of culture and working practices.

Furthermore, it requires:

- A good understanding of current practices and future trends
- Effective communication mechanisms of such processes, such as modeling
- Agreement of participating parties (Kagioglou, Cooper, Aouad, 1998).

As mentioned before, this is due to the fact that the processes in the construction industry are fragmented and parties look what's the best strategy for them and what's the added value of a project to their company. There are several contracts between the interfaces and between different players/stakeholders (client, advisors, contractors, subcontractors).

In UK a number of initiatives have been launched which aim to *borrow* or transfer established manufacturing principles at both project level and at the operational level Coordinated efforts of the Department for the Environment, Transport and the Regions (DETR), and the Engineering and Physical Sciences Research Council (EPSRC) were initiated to translate manufacturing principles into construction. (Kagioglou, Cooper, Aouad, 1998). Those efforts have led to the development of the Innovative Manufacturing Initiative (IMI) with a particular sector namely 'Construction as a Manufacturing Process' (EPSRC, 1998).

In 1993, M. Hammer and J. Champy suggested that re-engineering is "the fundamental rethinking and radical redesign of business process to bring about dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed."

The emphasis of this re-engineering was by the use of information technology.

It seems that in the UK, the resistance towards changing and innovative ways is less than in the

¹² Ad-hoc: generally signifies a solution designed for a specific problem or task, non-generalizable, and not intended to be able to be adapted to other purposes. A solution for that specific case or situation. (Wikipedia, March 2012)

Netherlands and in UK they more open to challenges. That could explain their lead in innovation.

The UK construction industry has been looking in the Manufacturing industry for potential technology and practices transfer, so that significant performance improvements can be achieved (Kagioglou, et. al. 1999).

In spite of the successful application of Quality Function Deployment (QFD) in the manufacturing environment, construction organizations are not yet reaping their benefits.

These results were not unexpected. A possible solution to this situation could be to encourage the application of improvement tools in the construction industry by tailoring them and developing frameworks for helping their implementation, as has been done in the manufacturing sector (David J. Delgado-Hernandez and Elaine M. Aspinwall 2005).

The researches vary from the nature of the industries to cultural dimensions of them. In the construction industry the idea or the job comes from the client and in some cases (e.g. D&C contracts) the maintenance would go to the client too. On the contrary in the automotive/manufacturing industry the idea is from the company and the using/maintenance of the product is for the client.

Also another major difference is the contractual barriers between the stakeholders which exist within the construction projects unlike manufacturing industry in which there's one major company that produces its products (Figure 11).

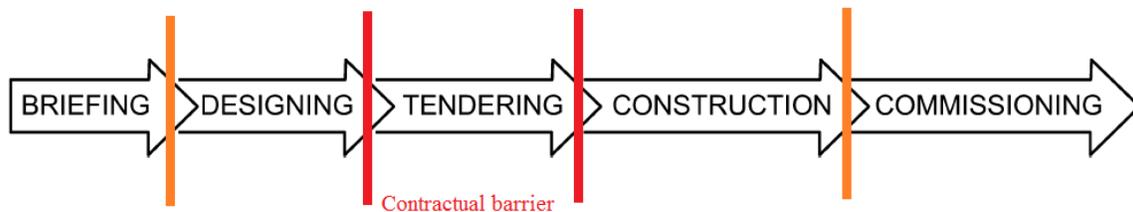


Figure 11: Contractual barriers within the construction industry

This fact makes the projects in the construction industry more fragmented and divided amongst several parties which reduces the feeling of trust between them and each party aims its own profit/benefit.

In Geert Hofstede's research the cultural issues have been investigated and the two industries were compared to one another.

Table summarizes the outcome of his research as the points mentioned in the table are understandable and clear.

Cultural Dimension	Manufacturing	Construction
(1) Process vs. (2) result orientation	<ul style="list-style-type: none"> - means oriented - risk avoidance - limited personal input - repetitive tasks 	<ul style="list-style-type: none"> - goals oriented - risk acceptance - high personal input - changing tasks
(1) Organizational vs. (2) professional	<ul style="list-style-type: none"> - norms of the organization are universal - identity is provided by organization - family life is important - personally short term orientation 	<ul style="list-style-type: none"> - private life and business life are separate - task competence is important - personally long term orientation
(1) Weak vs. (2) strong control	<ul style="list-style-type: none"> - costs are unimportant - meetings do not commence on time - many jokes about the company and work 	<ul style="list-style-type: none"> - cost oriented - meetings are on time - few jokes about the company and work
(1) Normative vs. (2) pragmatic	<ul style="list-style-type: none"> - keeping the rules - keeping the procedures - dogmatic view of ethics 	<ul style="list-style-type: none"> - customer orientation - result is more important than procedures - pragmatic view of ethics

Table 1: Dimensions of industry cultures (source: Brockman, C.; Birkholz, A., *Industry Culture in Construction and Manufacturing*, 2005.)

Because the projects in the construction industry are unique, the environment and the scope are changing and every time it's different while in the manufacturing the processes are repetitive. Also thanks to automatic machines, less personal or staffs are needed in many manufacturing companies compared to construction projects in its totality.

Brockman and Birkholz (2005) organize this comparison in two lines: input criteria and process criteria.

The inputs are labor, materials, and plant. For Germany the percentage of the total cost are 58% (construction) vs. 19% (automobile) for labor costs, 26% (construction) vs. 67% (automobile) for material costs, and 2% (construction) vs. 4% (automobile) for plant depreciation.

The remainders are other costs. In sum, construction is by this comparison three times as labor-intensive, 0.4 times as material-intensive, and 0.5 times as plant-intensive as the automobile industry.

The different process criteria are: site construction vs. assembly line production, mechanized vs. automated construction, discontinuous vs. continuous production, unit vs. mass production (Brockman and Birkholz, 2005).

Table 2 summarizes their findings in regard to differences between construction and automotive industry. Some elements are already mentioned in the previous tables.

Construction industry	Automobile industry
Environment	
Higher labor intensity	Lower labor intensity
Lower material intensity	Higher material intensity
Lower plant intensity	Higher plant intensity
Site production	Assembly line production
Mechanized production	Automated production
Discontinuous production	Continuous production
Unit production	Mass production
Structure	
Fewer levels of management	More levels of management
Not formalized	Formalized
Decentralized	Centralized
Much verbal communication	Little verbal communication
Organic structure	Mechanistic structure
Culture	
Not well defined	Well defined
Highly communicative	Little communication
Result oriented	Process oriented
Professional	Organizational
Pragmatic	Normative

Table 2: Difference between Construction industry and Automobile industry (source: Brockman and Birkholz, 2005)

Riley and Clare-Brown (2001), who researched the differences between the two industries, have similar findings.

Conclusion

The most important differences between the construction and manufacturing industries are:

- Contractual barriers between the parties in the construction industry due to the fragmentation nature.
- The uniqueness of construction projects and the change of environment and stakeholders in every construction project.
- Top-down approach in the construction industry versus bottom-up approach in the manufacturing industry.
- Client's influence on the project is much more in the construction projects
- In the manufacturing industry the requirements are fixed while in the construction industry they change according to client's demands/wishes and the environmental circumstances.
- Mass production in the manufacturing and more automatized process and more innovative products unlike the construction projects.

A tailoring process would make transition from one industry into another easier when a new methods or tool is introduced.

Chapter 5. Systems Engineering Towards Construction Industry

Efficiency and change in the construction industry is something that is being discussed among the experts. In the construction industry it is also desirable that the client orders and the market comes with solutions while thinking functionally (focusing on the problem and the demand and wishes of the client). Clients like RWS used to have a lot of designers inside the organization too who understood the design procedure and then when the draft designs were made, it was handed over to the contractor and even then RWS was very much involved so there was little room for the contractor to make new and its own solutions. Also many choices were done by experts just by intuition and experience they had and no underpinned arguments were used. That would not be a disaster in smaller project but when the projects become complex then making decisions explicit will be much more important. SE obliges one to make the decisions and choices along with analysis and checkups explicit and get structures. In practice SE is considered as a tool for control and checkups done by the client. In this chapter the needs for change in the construction industry is being highlighted and at the end one can see why RWS thought Functional Specification, which was the start of using SE, was a suitable methods and what it can bring about.

The fact that UK is a few steps ahead than the Netherlands regarding the innovative contracts and implementing new methods from other industries into the construction industry helps us to see a snap shot of the future in the Netherlands.

In the UK the implementation of Public Private Partnership (PPP) and Design & Construct or Design Build Finance and Maintenance (DBFM) form of contracts, have been started long time ago.

A UK Government investigation (Latham, 1994) confirms that there is need for improvement and change in the construction industry.

The report focuses upon the fragmented nature of the industry as a major factor contributing to the poor communication between all parties working on a construction project. Some of the major outcomes of this investigation are (Latham, 1994):

- Although a number of changes have been identified in previous investigations of the construction industry, the majority of them have not been implemented. *This shows that the construction industry might be inherently resisting to changes.*

This might be similar to the Dutch current situation of the construction industry in which the implementation of Integrated Contracts and using of SE has not been an easygoing process.

- Clients (customers rather than end users) are the main parties which could instigate (Dutch: aansporen/aanwakkeren) changes in the industry and therefore they have a responsibility and a part to play in this change process and none more than the government itself.

One can observe this in the Netherlands as well. RWS and ProRail as two main clients want to see changes and ask the market to be involved more. This was meant to shift the risks and responsibilities towards the market (e.g. contractors) and also to increase innovation and technology. This would create room for improvements and effectively and efficiency in the market.

- There is a need for more effective collaboration between clients and contractors.

Effective collaboration can be translated into more involvement of contractors from the earlier phases of the project. Contractors are more experienced in practical work and have other ideas as well and they now should have more space to use their experiences. That collaboration means also working towards more integrated contracts like D&C and Alliance.

- There is also a need for effective processes throughout the construction life cycle starting from the management of the client brief to the selection of the supply chain participants and eventual construction/on-site processes.

This can be achieved, according to RWS and ProRail, by using SE in the project to have more efficient and effective processes. The future will show if that works according to the initial goals of implementing SE.

The main outcome and recommendation of the Latham report is that it calls for significant cost savings by the utilization and formulation of effective construction processes which will in turn lead to increased performance (Kagioglou, Cooper, Aouad, 1998).

These recommendations were affirmed again in another report by Sir John Egan "Rethinking Construction" (1998) which reported on the scope for improving the quality and efficiency of UK construction. This report has identified five key drivers of change which need to set the agenda for the construction industry at large, and they include:

1. Committed leadership
2. Focus on the customer
3. Integrated processes and teams
4. Quality driven agenda
5. Commitment to people

(Kagioglou, Cooper, Aouad, 1998).

Also the report of Egan (1998) calls for a reduction of 10% in construction costs and time along with reduction of 20% of defects in projects annually. Therefore it's been said that a significant re-engineering of the construction process and sub-processes is required.

Dutch construction industry is quite similar to that of the UK in this sense. Dutch public works (RWS) is aiming to increase efficiency (reducing cost and time with less means) as well as increasing effectiveness (successful projects and reduction of defects).

This aim requires changes in the building industry and its process.

5.1 Tailoring Systems Engineering

Aslaksen et.al. suggest that a tailoring step is needed before implying SE into any industry (Figure 12).

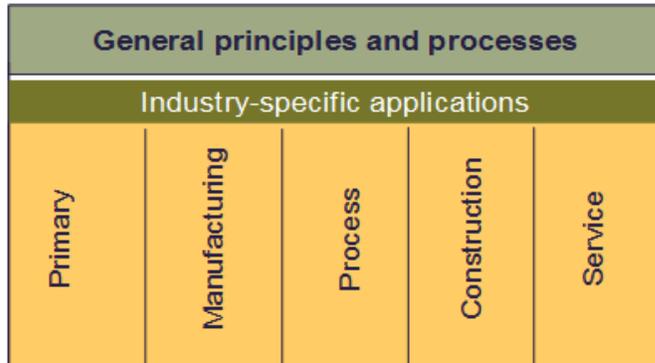


Figure 12: The “new” view of systems engineering (source: Aslaksen, E.W., et. al., Designing the Construction Process, page 2).

If we consider *the process of engineering* to be the application of technology to transitioning from a set of needs to an object that provides a service that meets those needs, then we can look upon systems engineering as the front-end process that reduces the complexity of that task to a level where traditional engineering can be applied with a high probability of success. There is nothing in this view that restricts systems engineering to any particular industry, but because the nature of the complexity, the particular features of the traditional engineering process to which systems engineering has to interface, and the language used, there needs to be a tailoring of the general systems engineering principles and processes to each industry, so that we should view systems engineering as illustrated in Figure 12 (Aslaksen, E.W., et. al., Designing the Construction Process).

The tailoring process and how it should be performed are out of the scope of this research.

5.2 Experiences with Systems Engineering

In the past, different researches were made and several theses have been written on what SE is and how its principles work. Although the principles and processes of it look logical and understandable, in practice things tend to work out differently. For examples the resistance from project leaders/engineers/managers demonstrates the undesirability of a change in the current building processes.

Working with SE is experienced as extra work for not much extra added value. It is difficult for the projects leaders and design managers to suddenly think functional oriented instead of solution oriented (Toelichting Systems Engineering, Witteveen+Bos, 2010).

The initial goal was to reduce the complexity of projects when using systems engineering. However, SE decomposes the solution (design) instead of decomposing the problem itself according to Van Zwieten's research (Zwieten van C., Systems Engineering; Een ontwerptool of een controlemiddel?, October 2011).

She also mentions that when SE is used in the current situation, the sub-systems are being designed and composed separately and independently. This is in contradiction to the goal of SE which would help to create an Integral Design solution.

SE does not give an insight into design problem as it is not a design method but it's a tool that can be used to structure the relationships between the requirements and solutions and objects. Van Zwieten also mentions that SE is a method for quality check in the projects through verification and validation. SE is an explicit way of working and therefore it can provide the parties the requirements they need in a structures way.

In SE design procedure the requirements are functionally formulated and that means very deep specified with details. Usually a design company is asked to help the client with that. In practice that leads to reducing the solution space for the designers in later stages.

Designers do not like much paperwork and want to use their creativity and intuitions more. Especially the verification is considered double work. Also very deep specifying of requirements is considered tiring and not useful. This also demotivates the designer to do his jobs well. Functionally specifying is not considered common in the construction industry. Many people have difficulties to describe things in a functional way. That's why they tend to look for a solution instead if looking into the problem.

In his research (Lever, A.W., Functioneel specificeren bij projecten van Rijkswaterstaat, December 2006) Lever focuses on Functional Specifying (FS) in the analysis phase by the client and in this case RWS. He goes deep into the (dis)advantages of that method and explains from the client perspective.

- FS is a suitable method for RWS. Despite the fact that not all the goals of implementing SE have been achieved in the projects, FS (and SE in general) can be seen as methods that provide good process in project. It makes working explicit, structuring the project and good using of information possible.
- The expectation is that goals of implementing SE will be achieved more in the future and thus the projects will become cheaper and better solution will be delivered.

According to Lever further points to note in regard to SE are:

- FS requires different people with a different way of thinking. Also it looks like FS along with leaving more room for the market to be involved in the design phase, will have consequences such as losing knowledge.
- Certain knowledge is really required to have when specifying functionally and composing good specifications. So, it's important to have and keep necessary knowledge inside RWS.

- There's not so much experience with FS and that's why it costs much money to teach the stuff. A good knowledge and information database and development of that can help preventing these extra costs.
- FS is used very late in the project and not right from the start and during the phases that FS is still not used; many things from the projects are already recorded and fixed. By starting earlier with SE and writing down less (not fixing), much more profit can be gained and this.

5.3 State of the Art of Systems Engineering in the Netherlands

In the research of Myrthe van de Gazelle (Gazelle van de M., *Samenwerken is vertrouwen, is loslaten, is delen en is leren*, September 2011) the state of the art at RWS in regard to using SE was investigated. This was a comprehensive research on the topic SE in general and its relationship to Systems oriented contract management and in particular Integrated Contracts especially from RWS's viewpoint in practice. The following were interesting findings for this research:

Systems-Oriented Contract Management (SOCM) and SE

- RWS and clients do not possess sufficient knowledge about Integrated Contract Management, SE, testing, and testing mix and verification & validation. Because of this fact, SCB and SE are not used optimal.
- RWS is still taking part in the design phase actively and uses SE as a tool for this while RWS and Clients are not aware of this.
- In practice, SOCM and SE do not lead sufficiently to the success in realization of projects and efficiency and effective results. This is because the new approach does not offer support for project- process- and network management which leads that SOCM and SE are not integrated in the organization (RWS) and other networks but also they are not interwoven inside the processes and projects.
- The current organizational fragmentation inside RWS prevent using SE optimally because RWS did not think deeper when it implemented SOCM and SE. That's why SOCM and SE support RWS insufficient to anticipate on the strategic behavior of contractors. This is similar to the fact that contractors find SE does not contribute to profiling contractors on the market.
- SOCM and SE are methods which need a period of time to be implemented. Application of IC and SE as instruments is improving; however the real meaning of them is not understood.
The problem is that RWS did not ask the right questions neither investigated before implementing SOCM and SE. That's why the methods do not answer the wishes and don't form a support and nor do they achieve the desirable results.

In brief Van de Gazelle argues that the current state of SOCM does not lead to successful realization while SE does lead to successful realization of projects. The same is valid in regard to efficiency and effectiveness of both SOCM and SE.

Finally she concludes that well developed SOCM and SE lead to an increase of successful realizations if RWS and contractors are both ready to be able and wanting to work with SOCM and SE. Also a developed SOCM and SE mean they should be pragmatic to increase success. Therefor RWS should invest in information transmission from RWS to contractors.

Conclusion

From aforementioned developments, one can see that it is very tough to change the traditional methods used in the construction industry to other methods. Even though there is need for change in the sense of efficiency and effectiveness.

Right now the construction industry in the Netherlands is experiencing changes too and this development can only be evaluated and judges unbiased in the coming years if higher maturity levels have been gained.

To understand what RWS means by using SE in the construction projects and how it hopes to get efficiency, one has to look at RWS's goals and practices further more. In the next chapter the RWS's approach in regard to SE is being investigated.

Chapter 6. Rijkswaterstaat Approach

ProRail introduced Systems Engineering in the Rail projects in Netherlands and later on RWS joined and started to implement this method in the Infrastructure Projects (GWW-sector). The Systems engineering used by RWS is introduced to reply the political and social demand for the Dutch government to reduce its involvement and the need to involve the market sector to a greater extent and at an earlier stage in the design, construction and management of infrastructure in the Netherlands. The call for transparency and better process control is another reason for RWS to use SE. This requires proper communication between contracting authority and contractor, whereby the parties verify and validate different options and solutions in a clear way. SE makes it possible to determine the level of effectiveness and efficiency. Does the solution meet the client's requirements to the maximum possible extent (effectiveness) and does the solution provide the best possible quality/price ratio (efficiency)? The life cycle approach is utilized in the SE used by RWS. Considering the entire life cycle during the design makes it possible to focus the solution on producing maximum performance and quality (efficiency) for the entire life cycle.

Shifting the responsibilities and the risks of the design and building phase more to the market, were reasons to introduce integrated contracts in which SE plays a major role.

For managing of its projects, RWS uses today the Integrated Project Management model known as IPM model. Within this model the following processes can be distinguished: project management process, environment process, technical process, purchasing process, project monitoring and project support. *In the IPM Model context, SE is primarily an approach to the technical process.*

There is interaction between the technical process and other processes. SE forms the basis for this interaction. Figure 13 illustrates the system context and responsibilities within a public work project.

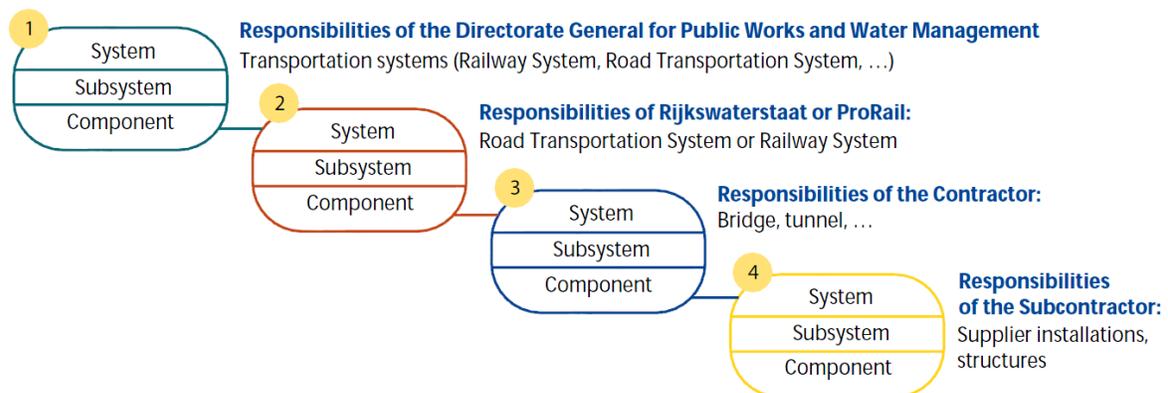


Figure 13: Top-down structure (source: Leidraad System Engineering, RWS, 2009, page 31)

A system is a set of related components intended to achieve a certain objective by performing a specific function. The way in which a system is viewed and defined is dependent on the interests and responsibilities of the observer (the so-called 'System of Interest'). Something that is a system to one person could be considered as a component of a system by another person. Complex systems are often subdivided into subsystems (or system components) that are in turn considered as systems. The reason for this is to ensure that the responsibility for producing these subsystems can be transferred to another party on the basis of a separate agreement.

The systems within the civil engineering sector generally have a wide range of stakeholders, both paying and non-paying stakeholders. The stakeholders set their own requirements for the system to be developed. All stakeholders are considered to be the clients and the set of their requirements to the system is seen as the clients' demand. RWS uses systems engineering mainly for specifying the clients' requirements. There are two types of requirements to distinguish: System requirements specifications (SRS) and process requirement specifications (PRS). SRS describes the requirements that must be met by the end product (the WHAT requirements). PRS includes the requirements that the development process used to produce the end-product is expected to meet (the HOW requirements).

6.1 Rijkswaterstaat Process Model

The starting point is to analyze the problems related to the clients' demand. This client's demand has been focused on the system determined by the paying client, being considered as his "System of Interest" and the intended use of the system. The client determines what the problem is and which solution space has to be considered and when it can be considered that the requirements are met. Indeed the demands of the not paying stakeholders have also to be analyzed for determining of the solution space. Thus, through systems engineering the optimal solution will be created within the solution space.

The next step is to analyze and to optimize the requirements of all stakeholders into systems specifications after a stakeholder analysis is realized. Which stakeholders are related to the system and what are their interests and requirements? SE in RWS translates then the clients' requirements into functional specifications and aspects specifications, together known as requirements specifications.

The aspects to be considered for a system are reliability, availability, maintainability and safety known as RAMS aspects.

RAMS analysis determines the boundary conditions for the system during its life cycle. The functioning of the system must be ensured within these boundary conditions. All steps in systems engineering are then directed to meet the optimum solution for the clients' demand. The system goes through several phases during its life cycle. SE has to be directed on the optimization of the system during its whole life cycle, considering the clients' demand at the center.

The engineering process, known from SE theory consists of three sub-processes: Requirements Analysis, Functional Analysis and Design. There is a loop between two consecutive sub-processes. At the end of the process, the design is compared to the specified requirements. This is the verification of the design against the requirements. The sub-processes are explained below on the basis of following Figure 14.

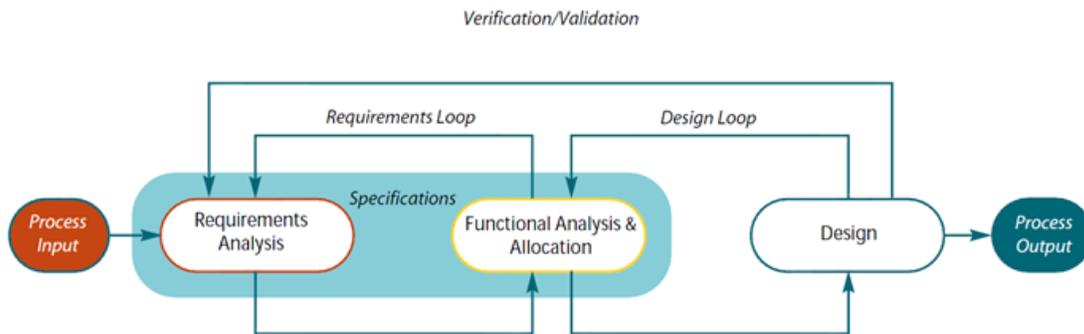


Figure 14: SE process model as by RWS (source: *Leidraad System Engineering, RWS, 2009, page 36*)

6.1.1 Process input

The input into the “engineering process” is the output of the “stakeholder requirements specification process” during which the needs of the stakeholders (contracting authority and stakeholders) are converted into requirements. This process always starts off with a problem and the related need(s) of the client/ contracting authority and other stakeholders.

6.1.2 Requirement analysis

The objective of the requirements analysis process is to translate the stakeholders’ requirements into SMART¹³ system requirements. The requirements for the functions of the system to be designed determine what the system must be able to do and must be functionally specified. The functions are therefore transformed into requirements during this phase and, where necessary, requirements are translated into more detailed requirements on the basis of the design choices made. At the same time other requirements related to regulations, environmental aspects, internal and external interface and RAMS- aspects are also addressed to determine the design boundaries.

6.1.3 Functional analysis and allocation

The objective of the functional analysis and allocation process is to transform the functions of a system into subsystems and to prepare a specification that documents the requirements that the relevant subsystem is expected to meet.

The functional analysis and allocation process includes the following steps:

- the detailed specification of all of the system’s functions
- derive the subsystems (function enablers) from these functions
- create structure and coherence among these subsystems
- link the requirements from the requirements analysis to these subsystems

¹³ Specific Measurable Attainable Relevant Timely, a set of objective in PM.

The inputs into this process are the functions of the system to be designed, determined on the basis of the contracting authority and/or stakeholders' needs. These main functions can be further decomposed or used for deriving sub- functions. The extent to which these functions are decomposed depends on the available information and the needs of a specific project phase. The decomposition results in a functional breakdown structure (Figure 15). The functions are subsequently transformed into solution-independent structured subsystems. A subsystem can perform one or multiple functions.

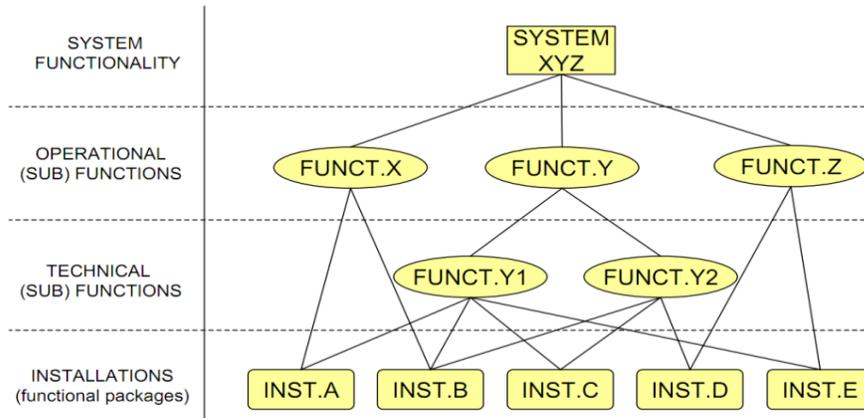


Figure 15: Functional Breakdown Structure (source: Leidraad System Engineering, RWS, 2009)

6.1.4 Requirements loop

The functional analysis provides insight into the points where the requirements analysis process was lacking. The requirements loop then returns to the requirements analysis and the analysis is repeated. This transforms the requirements analysis and the functional analysis into an iterative process that can be repeated several times. This iterative process is referred to as the requirements loop.

6.1.5 Design process

During this phase, the subsystems are actually developed in accordance with the functional analysis. In other words: a solution-independent subsystem is transformed into a physical solution-based sub-system. The design must meet the entire set of requirements, as determined for each object in the functional analysis. This means that the design must not only meet the functional requirements, but must also meet the various aspect related requirements. The design process is subdivided into a number of interim steps to promote the manageability, reproducibility and efficiency of the design process.

- *Generate options and reduce options*: The objective of the options generation and reduction process is to determine the possible solutions for a system and to produce a limited number of feasible options on that basis that will be subjected to further investigation. The generation of options is defined as the consideration of all possible solution directions for the system. In order to be able to produce a comprehensive list that does not 'overlook' any potentially acceptable solutions, it is important that the

- initial survey of options be determined without any consideration of value whatsoever and to stimulate out-of-the-box thinking during the options generation phase.
- *Variant development*: The objective of this step is to be able to make a design choice for the system under consideration that best meets the requirements and other criteria such as costs or environmental impacts. A score matrix or a trade-off matrix is used to allow the variants to be compared. The different assessment criteria are assigned a weighting factor. The variant with the best score (or that represents the highest value) is ultimately selected as the solution for the system.
 - *The detailed design*: The design selected as the solution of the system is developed in further detail during this phase. The requirements or functions attributed to the subsystem or process are defined in specific terms at the desired level of detail.

6.1.6 Design loop

The design loop (Figure 16) represents the verification of the fit of the design and the subsystems with the requirements.

It is possible that during the preparation of the design it becomes clear that a certain allocation of requirements or functions is not desirable. In addition, functions that have not yet been described may emerge. In all these instances it is necessary to return to the functional analysis and to incorporate these new insights into the functional specifications. Once this is done the design can be restarted or resumed. Due to the fact that the functional analysis can be carried out several times, a design loop emerges.

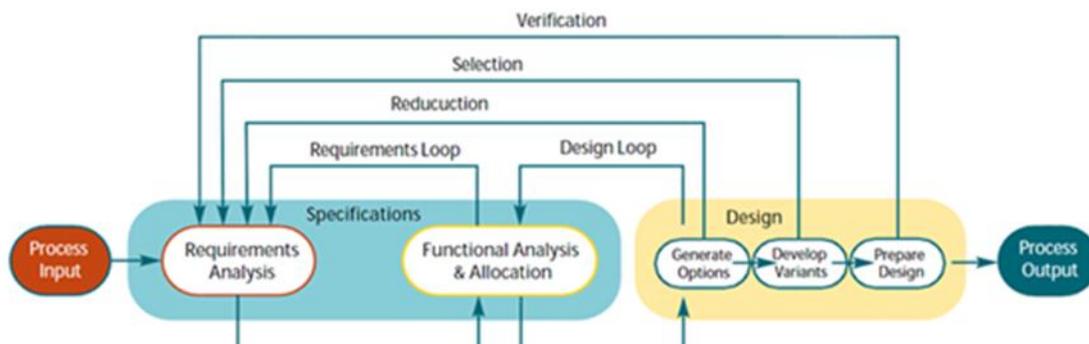


Figure 16: Detailed process model by RWS (source: Leidraad System Engineering, RWS, 2009, page 41)

6.1.7 Verification

Once the design process is complete, the verification process is initiated. The objective of the verification process is to objectively demonstrate that the design matches the requirements. Deviation from the requirements that are noted during the verification process results in a proposal for corrective actions. In general, when the specifications for a subsystem are prepared, a verification plan is prepared for that subsystem as well. Once the subsystem is designed, a verification report is prepared which documents whether the design meets the specified requirements or not.

RWS has determined a set of principles to be considered during the implementation of systems engineering in its projects. These principles are guiding the cooperation within the civil engineering sector. They indicate what the parties involved can expect from each other. These principles are presented below:

- 1- Client's demand at the center: All steps within the process of systems engineering should focus on meeting the requirements of the client (all stakeholders).
- 2- Systems thinking: One of the important fundamental principles in systems engineering is systems thinking. A system is interpreted as "a set of related components that contribute to a joint goal in an organized way". Systems-thinking considers complex problems and potential solutions from a holistic perspective. The problem is viewed in the context of the larger whole. The way in which a system is defined depends on the interests and responsibilities of the observer ('System of Interest'). Something that is a system to one person could be considered as an element of a system by another person.
- 3- Transparency: It has to be clear for every related party which choice for what reason is made.
- 4- Efficiency as described before.
- 5- Best ratio of price/quality.
- 6- Balance between design flexibility and contractual arrangements: Design freedom is desirable to increase the creativity of the market to achieve the best price/quality ratio. The design flexibility of a contractor must be in balance with the contractual arrangements. Employer and contractor must have a clear picture of the available solution space. The employer is responsible for specification of the solution space. This solution space has to fit within the clients' demand. The contractor must ensure that the offer fits within the solution space created by the employer.
- 7- Verification & Validation: The development process and the developed products have to be checked whether they are done properly and meet the requirements of the client.
- 8- Coordination with project management: Systems engineering focuses on the development and realization of the contents of a system. There are also overlapping with the management of the system, such as configuration management and risk management. The design of these processes requires a careful coordination between project management and systems engineering.
- 9- Open communication: As a result of iterative nature of systems engineering the employer and the contractor should communicate openly. They have to keep this in mind for decisions, background information, system options and risks. The parties must share all information necessary for proper interpretation of the problem and substantiation of the solution.

Within the SE process every single system can be split into subsystems and then into components in order to reduce the complexity of the system to be developed. The requirement for each part must then be specified in relation to the requirements specifications of the entire system. The design process of the system runs parallel to the specification process. The process

of SE proceeds on the basis of both processes. This process is repeatedly refined until a design emerges that is suitable for production. The requirements specifications and the design often merge at the lowest level (Leidraad Rijkswaterstaat, 2011).

6.2 Rijkswaterstaat's V-model

In the engineering projects different models are used for overviews and simplifying the process. Also in the construction industry various models are used in different disciplines. For infrastructure projects, RWS uses the so-called V-model.

Beside the V-model there are other models as well like Waterfall¹⁴ model and Spiral¹⁵ model which can be used for project management as quality check models. They have almost the same principles. RWS has chosen the V-model to be used in the construction project as the main model. It may be considered an extension of the waterfall model. It is important to note that the v-model has evolved over time and supports flexibility and agility throughout the development process. In addition to being a highly disciplined approach, it promotes meticulous design, development, and documentation necessary to build stable software products. Lately, it is being adopted by medical device industry (Wikipedia, June 2012).

RWS notes that it does not matter which of these models are used and it is only important that a model helps to understand and manage the system (Leidraad Rijkswaterstaat, 2011).

The V-model as used by RWS (Figure 17) is based on three important SE aspects:

- 1- Separation of specification and design
- 2- Verification and validation
- 3- Life cycle as the starting point

¹⁴ The **waterfall model** is a sequential design process, often used in software development processes, in which progress is seen as flowing steadily downwards (like a waterfall) through the phases of Conception, Initiation, Analysis, Design, Construction, Testing, Production/Implementation, and Maintenance.

The waterfall development model originates in the manufacturing and construction industries; highly structured physical environments in which after-the-fact changes are prohibitively costly, if not impossible. Since no formal software development methodologies existed at the time, this hardware-oriented model was simply adapted for software development (Wikipedia, June 2012).

¹⁵ The **spiral model** is a software development process combining elements of both design and prototyping-in-stages, in an effort to combine advantages of top-down and bottom-up concepts. Also known as the spiral lifecycle model (or spiral development), it is a systems development method (SDM) used in information technology (IT). This model of development combines the features of the prototyping and the waterfall model. The spiral model is intended for large, expensive and complicated projects (Wikipedia, June 2012).

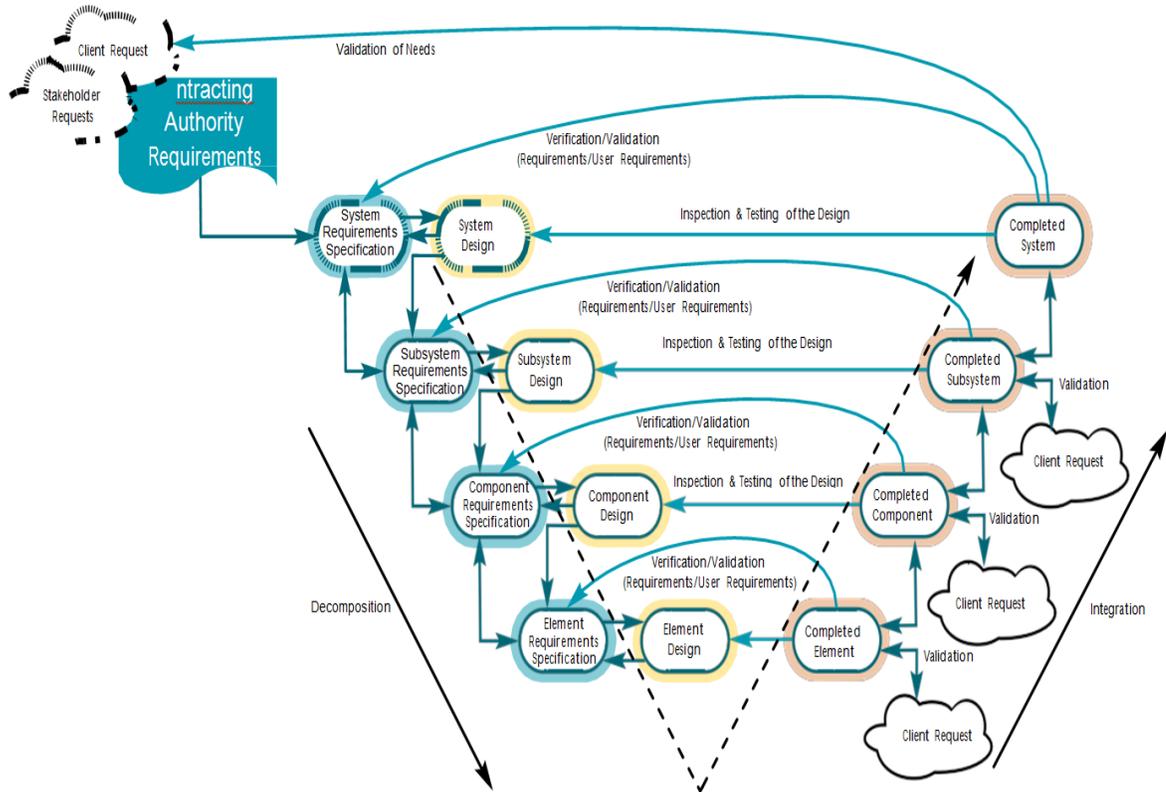


Figure 17: V-model used by RWS (source: Leidraad System Engineering, RWS, 2009, page 17)

Engineering process: Engineering process has three main components: requirement analysis (translate the stakeholder's requirements into measurable system requirements and function), functional analysis and allocation (transform the functions of a system into subsystems and to prepare a specification that provides the requirements that the relevant subsystem is expected to meet), and Design (subsystems are actually developed in accordance with the functional analysis).

Production process: In contrast to engineering process, production process is performed down to up and it joins and assembles the outputs from each level of detail, which is carries out during the engineering model.

Lifecycle process: System engineering provides the needs of the stakeholders for the entire lifecycle. It means that, we can use V model during the lifecycle of the project, in the design phase, operate and maintenance phase, renew phase, and also for deciding when to retire and stop the project.

In the V-model the emphasis is much more on Verification and Validation (V&V). The V is refers also to those steps which are necessary action when making a product and things need to be checked immediately in every phase of a project when using SE.

So right after the requirements are made a V&V procedure should be done and then in the design phase again. Basically in the V-model each phase has a realization step (deliverable) which is verified against the initial requirements and validated as well.

The model has a V-shape (Figure 17). The descending line to the left represents the further detailing of specifications and design process (decomposition) and the ascending line to the right represents the production process (integration).

This figure might give the impression that there are four levels of specifications. Though complying with the described series in Figure 17, it must be mentioned that the amount of levels depends on the complexity of the system. A complex system needs to go through the specification process more often than a simple system.

Based on the specified requirements, the design is prepared. After this, the design is verified to determine whether the requirements are met. Subsystems, component and elements are subsequently designed accordingly and then verified. The top down design process starts at the system level and goes downwards more in detail to the element level through the descending line. At each level the design must be verified to the requirements specifications. After that the design must be executed. This process starts from the lowest level (element level) and runs through the ascending line upwards to the system level. Every level of production has to be verified whether it is in accordance with the design and must be validated whether it meets the clients' demand.

6.3 RAMS

RAMS (reliability, availability, maintenance, and safety) requirements are very important in making lifecycle exchanges. These requirements are normally used for infrastructure system, but now it is mandatory for railway transportation systems, too.

The projects to be developed and executed by RWS are more public works and water management systems. One of their characteristics is that these processes can be renewed during the user phase and can be executed several times during the system's life cycle. The repetitive execution of specification, design and production during the life cycle is graphically represented in the following diagram. During operating, maintenance and renewal phase, the V-model is basically used for requirements specifications and verifying of the execution process and product. However the operation, maintenance and renewal process is less expanded than the process for a new project (Figure 18).

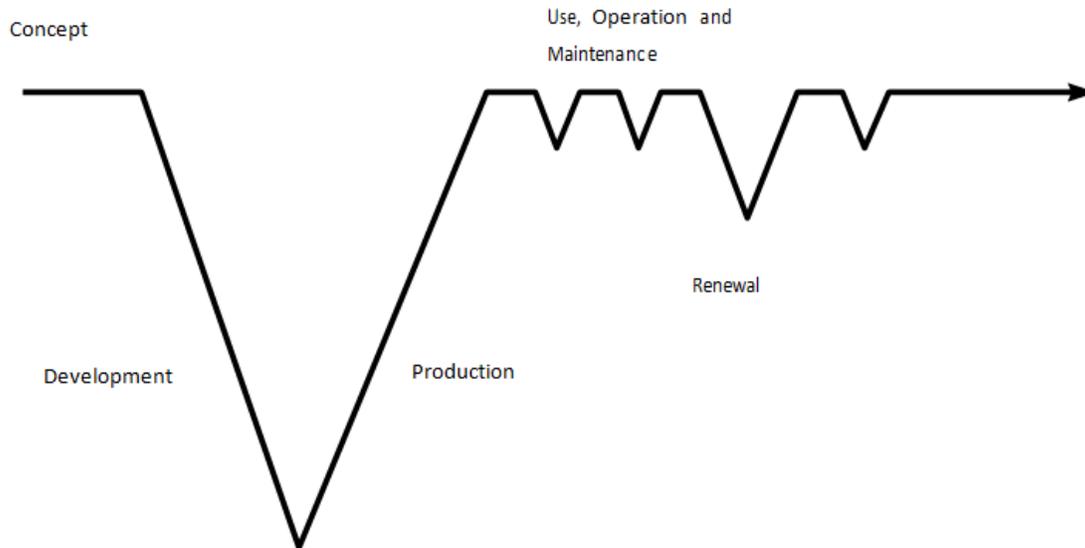


Figure 18: Simple V-model (source: *Leidraad System Engineering, RWS, 2009, page 18*)

Once a system is realized and operational, adjustments to the system might be necessary due to changing requirements. For every adjustment or modification, another V can be added. However for the later V's the design process does not start from scratch as for the earliest V, but it has the specifications made during development of the system as a starting point. If adjustments appear to be complex, the specification process has to be carried out several times again.

As a general concept, process depicts an action of taking something by means of established and usually (norms) routine set of procedures or steps to transform it from something to another thing, any process can be described as a behavior. In the engineering context, process involves in a set of converting of input elements to output elements with specific properties, along with the transformations characterized by parameters and constraints.

6.4 Management and Technical Processes

The system engineering process divided into **system engineering management process**, and **system engineering technical process**.

The systems engineering management process, itself, is broken into three pieces: project planning, review and re-planning, and change control.

The V-model is designed to represent the sequence of steps in a project lifecycle development and it described the activities and designs that have to be created during the system development.

Basically, the V-model illustrates the separation of specification, design and production along with further detailing of the system to sub-systems, components and ultimately elements. Also it structures the verification and validation of the design and production against the requirements during the system life cycle.

To be able to properly manage the complexity of a system, a top-down approach to the engineering process is essential. Depending on the complexity of a system and the level of detail

to which the system has advanced, the engineering process as described before is repeated one or more times from the highest level down to the lowest level. The iterative engineering process at different levels of detail can be linked together through means of decomposition, traceability, design integration and requirements derivation.

In public works, a problem can be discerned at any level of detail. The system is further decomposed at each lower level of detail in the engineering process until a level of detail is reached where the design is ready for production. The ultimate result of the engineering process is a production-ready design for the system to be constructed.

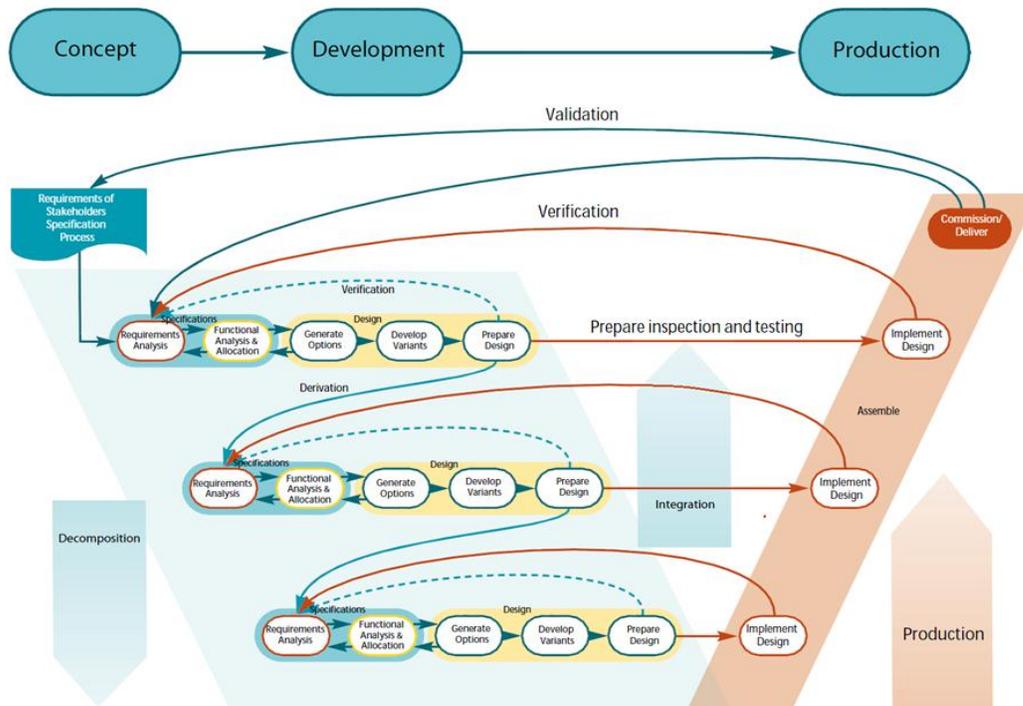


Figure 19: All phases in V-model, detailed (source: Leidraad System Engineering, RWS, 2009, page 47)

The engineering process whereby the design to be produced is defined, is followed by the production process. The system is actually, physically produced during this phase. Like the engineering process, the production of complex systems is carried out in layers. In contrast to the engineering process which is executed top-down (from highest level to lowest level), the production process is carried out bottom-up (from lowest level to highest level). The production process consists of a number of sub-processes or activities: the joining or assembling of subsystems, the inspection and testing of subsystems and the validation of the system. Inspection and testing equates to verification in the production process.

Figure 19 illustrates the V-model containing various sub-processes together with their relationship to the engineering process. It depicts the link between the iterative engineering processes and production process at various levels of detail.

Verification is the process of determining that a model implementation accurately represents the developer's conceptual description and specifications that the model was designed to.

Validation is the process of determining the manner and degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model, and of establishing the level of confidence that should be placed on this assessment.

Usually validation occurs at the end when the product is realized. At that moment the client with the contractor can see if all previous activities have led to the product that is according to demands and wishes of the client.

In practice it seems that actual validation of all requirements is difficult. For example if the demand for the life of a construction is 50 years then at least after 50 years it can be proven that the product meets all the requirements.

In some cases the validation of a requirement would be a combination of verification of sub-requirements in lower level (SE Leidraad of BAM Infra, 2008).

Conclusion

SE comes from a different industry into the construction industry. RWS and ProRail introduced SE in the Netherlands in construction projects (Infrastructure) and this decision was mainly made to reach efficiency in the projects with more effective results.

SE consists of a number of steps namely: Process input, Analysis, Design process, Verification, Validation and finally the Realization of each phase.

During Analysis step the demands and wishes of the stakeholders, while taking risks into account, are gathered and transformed into functional requirements. After this, they are being integrated into the designs and then the designs are tested against the requirements to make sure they meet all of them. If the designs are also validated by the client then the realization of that specific phase is done. And the same procedure can be repeated in the next phase. This is illustrated in the so-called V-model (Figure 19).

This information will be considered when answering the sub-question 1 about the initial goals of SE. Also when making questions for the interviews to see how SE is being experienced and implemented in practice, this chapter will be useful.

Also to understand to see what the state of the art in using SE in the Netherlands is right now. After the practical part, one can see to which extent the initial goals have been achieved and what the shortcomings and potentials of SE are within the construction projects and how these could be improved.

Chapter 7. Applicability of Systems Engineering

In this part the personal suggestions of the researcher himself will be discussed. This can be considered as the intermediate findings based on the literature study, observations of the theory so far and rational arguments. Also the interview questions are being composed and the research questions are considered as well. After this the practical part of this research can be performed in the next phase.

The differences between the two industries in the previous chapter could explain the compatibility of SE in the manufacturing industry and why it was developed there. In there, the requirements become fixed and the systems need to be composed while many verification and validation activities are necessary to deliver good quality products. The contractual barriers due to fragmentation in the construction industry, the changing environments and new stakeholders in every project, make the construction projects unique and very dynamic.

But also the culture within the construction industry plays a major role and that causes the same habits (of using intuition) for many engineers. That culture forces an engineer to use his intuition and previous experience in order to find a solution. And making every decision and choice explicit is then not a must for the designers.

It doesn't mean that more explicit work is not possible in the construction world. But because of time and cost pressures, one can imagine how the civil engineers or project managers would like to perform their jobs the way they are used to.

7.1 AHP Tool for Trade-offs

To show how AHP (Analytic Hierarchy Process) can be used for determining the weights of the criteria a simple example is given in Figure 20.

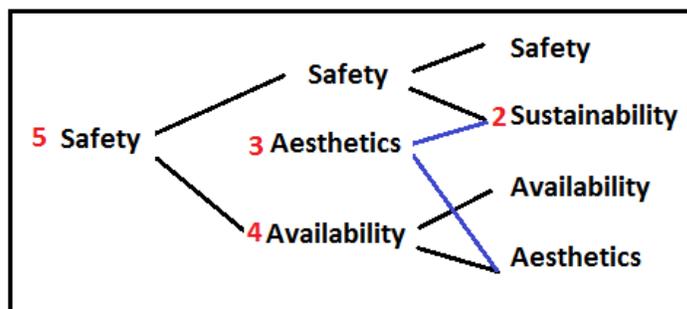


Figure 20: Pair-wise analysis

Figure 20 depicts a pair-wise analysis to see which weights the criteria get. One can choose, according to his/her performance which of the criteria is more important than the other. At the end the most left criteria gets the highest score and the most right one gets the lowest. The client (or stakeholders) with consult of experts can determine the weights in a short time. Choosing from a pair of criteria is much easier than scoring ten criteria at a time.

7.2 Applying QFD in Construction Projects

Figure 21 shows a simple example on how the House of Quality from the QFD methodology can be used in the construction projects when starting a project. For this imaginary project a large bridge should be constructed in a city.

This overview can be used in the analysis phase as an easy accessible table to make sure all requirements have been mentioned. Also one can see very quick which requirements contradict/support one another and it can be expanded as well to see more ratings and weights.

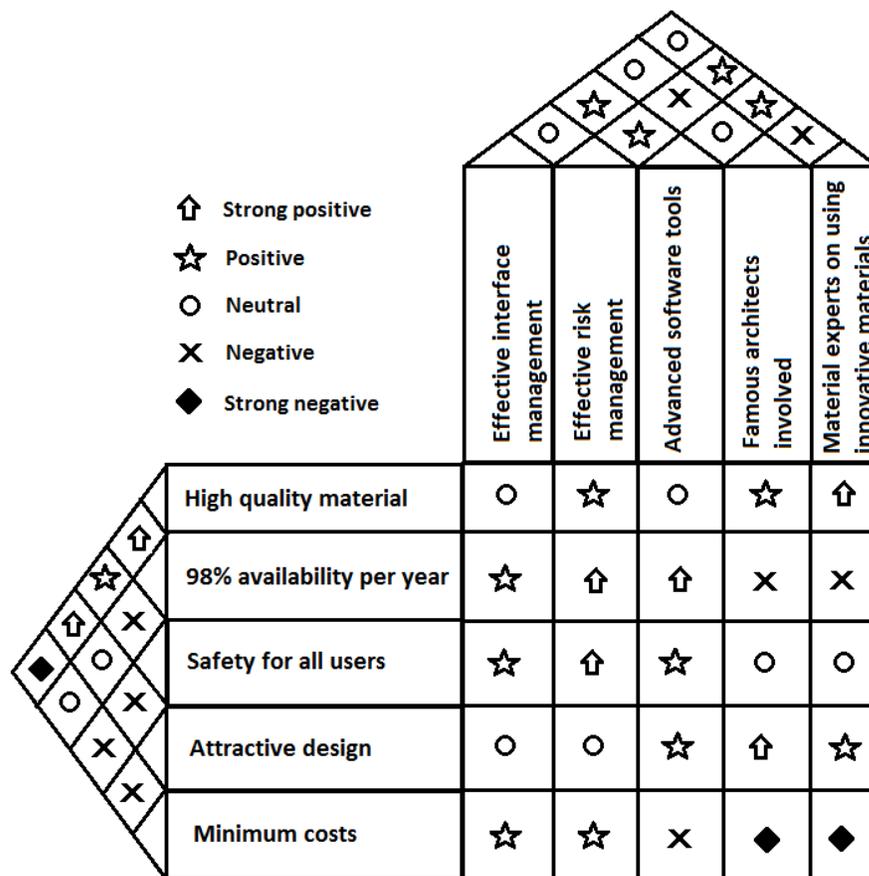


Figure 21: QFD applied in a construction project

On the left side the requirements are from the client. One can see that ‘minimum costs’ and ‘high quality material’ are in contraction. Also for the ‘attractive design’ and ‘safety for all users’ the ‘minimum costs’ might be a threat.

On the top, one can see how those requirements could be achieved. The level that these methods would influence one another is given as well on the roof.

In the body of the table where the requirements and the methods are being considered, one can see that Risk management is very positive for all the requirements. The options ‘involving

famous architects' and 'material experts' are obstacles for having low costs but yet positive for having an attractive bridge in the city.

Such a table helps one to have a good overview of the main requirements in a project along with their status in regard to other requirements and the way they should be achieved.

7.3 Contractual Barriers and Systems Engineering

As mentioned in previous chapters the contracts form a barrier between the client, advising/designing company and the contractors (Figure 22). Unlike manufacturing industry, in the construction projects this causes lack of trust between the parties since they do not form one whole company. It is possible that these parties do not see one another after the project's end and that is why they only think about their short-term benefits.

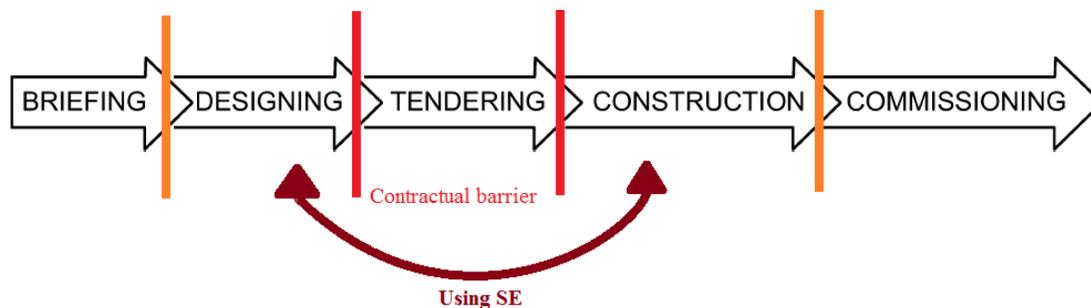


Figure 22: Contractual barriers in between using SE

SE should be used in different phases and the contractual barrier can cause misunderstandings and bad communication and these lead to result which still don not fulfill the wishes.

7.4 Research Questions

The current process of building infrastructural projects is not considered efficient, neither effective. According to RWS and contractors, a further professionalization and interaction of Integrated (innovative) Contracts and SE lead to more efficiency and effectiveness in the Infrastructure sector (Gazelle van de M., Samenwerken is vertrouwen, is loslaten, is delen en is leren, September 2011).

This answers the **first sub-question**¹⁶ in brief regarding the initial goals of using SE in the construction projects in the Netherlands.

With the introduction of Integrated Contracts in the Dutch construction industry, most phases are shifted towards the market along with most of the risks. This gives the contractors more space and motivation for innovative thinking and more functional oriented. That means pushing the risks towards the contractors which is less attractive for them.

The client can, instead of designing and taking the risks, validated the solutions to see if they fulfill his wishes and whether the designs meet all the requirements.

¹⁶ What were the initial goals of applying systems engineering in the construction industry?

To make sure that the solution and choices the designers have made are underpinned, they should prove these with justified arguments. This means that the choices need to be explicit instead of having them in mind only.

Since SE requires a deep analysis phase, trade-offs during the design phase and also verification against all the stakeholders' requirements, one should be able to compose underpinned and explicit arguments for the choices made but especially for the client's validation which happens in the later steps.

Traceability and transparency thank to using SE is very beneficial when a requirement changes or a choice needs to be explained or justified later on. The project manager/designer would easily see the reasons for making a specific choice and trace them back to a stakeholder and the initial requirements.

To examine the hypothesis of this research further investigation is necessary in order to find out how SE is applied and experienced in practice. That is performed by asking the experts and experienced engineers/projects managers through interviews and case studies.

With the interviews and case studies it is possible to notice whether the initial goals of using SE in the construction industry have been achieved and to which extent. These answer the **second sub-question**¹⁷ of this research and help us to find the potential deficiencies.

A list of question is thus necessary which addresses all these issues after the practical part has been performed, the **third sub-question**¹⁸ can be answered which enable us to get all the ingredients for answering the **main research question**¹⁹.

¹⁷ Considering the current application of systems engineering approach within the Dutch construction industry, to which extent have the initial goals of SE been achieved?

¹⁸ How can the system engineering approach be improved for application in the lifecycle of construction (infrastructure) projects?

¹⁹ What does the Systems Engineering approach contribute to efficiency and effectiveness in (complex) infrastructure projects?

Chapter 8. Practical Research

In this chapter firstly the interview questions are composed and then the process of the practical research is going to be explained. After these, the findings and results from interviews and case studies are presented. To make it easier for the reader the contents of interviews (the answers) have been moved to the Appendix of this report. For the practical part it is necessary to gather enough data which enables us answering the research questions and to test the hypothesis of this research. The main objective of this research is to see if using SE in the construction industry (infrastructure projects) makes things more efficient and effective and what the added value of SE is in this industry, whether the initial goals of implementing SE have been achieved, what the shortcomings are and how these could be improved.

For the interviews a group of experienced managers and project leaders and designers were chosen after consulting the supervisor at the company.

All these people work for DHV and some of them are detached to another company/agency like RWS or a contractor.

It seemed that DHV itself has invested very much in implementation of SE in the Netherlands and recently it is been made compulsory to use SE as the main approach inside the company. Because of this fact the project leaders have worked for both clients and contractors or in corporation with them and therefore most of the interviewees had insight into the entire project cycle.

The group of managers was asked about general aspects of SE and that is why those interviews were shorter and could give an overview from a managerial perspective.

The other interviews were more detailed and all design aspects from analysis to realization were covered. To make it more comprehensive a broader range of people was interviewed in the sense that other disciplines than infrastructure were involved as well such as :Water, Rail, Aviation, Real state and Buildings departments.

8.1 Interview Questions

The interview questions (see Appendix) are divided into different sets and they cover all the phases in a construction project when using SE. The main steps of SE are taken according to RWS model (See Figure 14) in Chapter 6.1: Input, Requirements Analysis, Functional Analysis & Allocation, Design (synthesis), Trade-offs, Verification & Validation loops and finally the Output. It is important to know if all these steps are being used correctly in the practice and how they are being experienced and understood.

After that, the general questions regarding SE theories are being considered to see how the interviewees look into the SE as a method and whether or not they understand how SE really works in the practice. These questions will be covering topics from Chapters 6.2 and 6.3 as well as Figure 15 which talk about the top-down approach of the V-model and decompositions and

(sub) systems.

Finally, the obstacles and deficiencies of applying SE and the personal opinions of the interviewees in regard to potentials and improvements of SE in the construction projects have been considered too. This last part is particularly meant for the general managers and head of the departments who are able to give managerial answers but also the engineers and project leaders who have more insight in the technical aspects and the applicability of SE into the infrastructure projects.

These sets of question along with the literature study part will enable the researcher to find conclusions and recommendation for this report.

8.1.1 The introduction set

The first set of questions cover the introduction part of the interview. In this part the interviewee introduces himself and he talks about the projects in which he was involved and SE was used as well.

These questions give an impression of the interviewee's background and to what extent he can give an opinion regarding SE related topics.

Also the interviewee is asked about his knowledge of SE and its application in the practice and how he gained this information or knowledge. This makes it more clear where the interviewee's perception comes from and whether his comments and opinions are based on particular course work, workshops, and self-study or just on the job.

SET 1: Introduction, projects involved and info about SE

1. Which project(s) have you been involved in which SE was applied?
2. What was your job in that particular project?
3. In which phase is this project right now?
4. Has there been enough attention given for acquiring knowledge about SE and its application, at the company?

These questions help the researcher to analyze interviewee's answers more objectively since the source of knowledge and information is known. Also a better picture of interviewee's perception and insight in SE and its application in the construction projects will be recognized.

8.1.2 The analysis phase set

This set of questions is divided into two parts. The first part is meant to know **which** information and data are collected and needed to perform the analysis phase in a project.

Through these questions we can find out what kind of lists there are available before starting the design works and whether the requirements are composed according to SMART²⁰ criteria. Another important question is if the problem formulation is clear before a project starts. If a problem definition is not well formulated and not understood by the engineer, then that will

²⁰ Specific, Measurable, Attainable/Achievable, Realistic and Time-sensitive.

decrease the chance of success. During the analysis phase, SE requires a clear problem formulation which should be available to all team members in a project.

SET 2, Part I: Information and collecting data before starting a project

5. Is there a list for requirements (demands)?
6. Is there a list for wishes/preferences?
7. Are the requirements composed SMART?
8. Is there a structure in the list with demands and wishes?
9. Do you find this structure useful?
10. Is there a clear problem formulation?

Because SE structures the project and makes all steps explicit, it should be clear what the problem definition is and what the objectives of a project are so that everyone in a project can look back to see and recall these quickly. That helps when the team members are in the middle of the project and the focus on the problem has decreased which might lead to irrelevant choices or less thoughtful decisions. By asking this set of questions it is aimed to find out if the first part of analysis phase is done properly according to the SE theory.

The second part consists of the actual action and performed tasks during the analysis phase. Questions are about **how** the information or data is gained and whether or not everything is double checked (data verification) before using them in the project.

SET 2, Part II: Actions during analysis phase

11. Are the requirements double checked? (conflicting, consistency, completeness etc.)
12. How is it handled with the conflicting, incomplete or critical requirements?
13. Is the given information sufficient to start the design works?
14. Through which way are the required information gained?
15. How does the communication occur with other actors in this phase?
16. In which way is the client involved in this phase?
17. Is there a link between the requirements and the stakeholders?
18. Are the requirements allocated to the design objects?
19. Has a risk analysis been performed before making further decisions?
20. Which tools are used during this phase?
21. What is the output and are there other documents produces in between?

Furthermore, how the conflicting and inconsistencies in the requirements are dealt with and how the communication occurs between the design team and the client as well as other stakeholders.

SE emphasis on an explicit way of working and due to structuring the project problems and goals all team members have to experience that. This set of questions should clarify whether that happens and how that happens in a project.

Risk analysis is an integral part of SE approach and it is going to be asked whether a risks analysis is performed and to what extent it is used throughout the project. A risk analysis from the start and keep updating it throughout the project could foresee the risks in the future and how to deal with them later on. This reduces the chances of failure or huge cost overruns. So it is important to know how a risk analysis is being performed and applied.

Finally, as each phase produces outputs, here it is interesting to know which output is expected or supposed to be delivered at the end of this phase. This is asked to see if the expected deliverables and the actual ones are the same and if it is not the case, then why and where did things go wrong? But also it is a look into interviewees' insight to find out what their awareness of this phase is.

8.1.3 The synthesis set

In this set the questions are related to the design phase. The interviewees have to explain how they start designing with the information from the previous phase and how they make sure that all the requirements are considered and used.

SET 3: Synthesis Phase

22. Is the information and data from the previous phase sufficient to generate design alternatives?
23. Are alternatives developed in each phase (concept design and final design)?
24. How are the requirements used during the design?
25. Is there a clear design scoop based on the available specification?
26. How is the client involved in this phase?
27. Are there interim decisions made for the design?
28. What kind of output is required?
29. Which output is generated but not required?
30. Are there any other documents generated in between?

Also the communication with the client during this phase is being questioned as well as the output that is expected at the end of this stage.

This is an essential phase in which the actual design takes place. It is important to know which decisions are made and how the requirements from previous phase are linked with the objects and options.

8.1.4 The evaluation set

In this set of questions the interviewees are asked how they make decisions during the project life cycle, particularly in the design phase, and whether or not they use trade-offs. Attention is given to the criteria and their weights but also the way each alternative gets a score in an objective way.

SET 4: Evaluation, Trade-off and its criteria

31. Is there sufficient information/data available for evaluation?
32. How is it made sure that the all evaluation criteria agree with the demand?
33. How are the subjective and non-measurable criteria taken into account?
34. Are the criteria considered in regard to usability , maintainability, feasibility, demolition and life cycle costs and how?
35. How do the criteria get a score, how are the alternatives valued?
36. Is there one evaluation moment or are there several moments in between as well?
37. How is the client involved in this phase?

During the design many decisions are taken, particularly in regard to different options and alternatives. It is important to know if there are certain ways used to make trade-offs and how the designs are linked to the initial requirements and different stakeholders because SE requires explicit approach during this process. These questions can help to see if evaluation regarding the alternatives/variants is understood and performed correctly or not.

SET 4.1: Trade-off tools

38. Are there certain evaluation methods used?
39. Is there special software used?
40. Is there any other tool used?

In a separate part of the same set which is related to evaluation set, the questions are about the tools which are used during the evaluations. Tools make works more efficient and speed up the progress. Each company can have its own tools but generally speaking, their principals are the same.

8.1.5 Verification and Validation (V&V)

In this set of questions special attention is given to the verification and validation methods and what the designers or project leaders expect from such activities.

SET 5: Verification &Validation

41. Is it required to demonstrate the design performance (to the client)?
42. Which actions are executed by a designer to demonstrate the incorporation of requirements in the design?
43. How are the subjective (biased) and hard-to-measure requirements demonstrated?
44. How does the validation take place?

V&V is an essential and integral part of SE and hence it is needed to find out whether it is understood and performed the way it is required from the theory which is supposed to lead to good quality product as demanded and wished by the client. It is interesting to know how the validation takes place and how the designs are tested against the initial requirements.

8.1.6 Top-down and revisions

In this set of questions the interviewees have to explain whether they design/manage in a top-down or bottom-up way. That will enable the researcher to see if SE is understood and practiced according to the theory (e.g. the V-model approach) and if not then why.

SET 6: Top-down, Bottom-up, changes in design and revisions

45. Do you go through all steps in every phase?
46. Are things designed in top-down or bottom-up way?
47. Is it possible to design top-down?
48. Are the design choices revised often? What are the cause and the effects of such revisions?
49. Do you go through several design cycles when designing one phase (preliminary or final design)?

A very important question is in regard to revisions and how to deal with such cases and what the consequences of such changes are for the final product. Theoretically it is easier to bring changes to the design in even later phases if SE is applied because everything is explicit and structured well and all requirements, stakeholders and objects are linked to one another. But how is that experienced and understood in practice and does it work or not?

8.1.7 Decompositions and interfaces

Since decomposition is a part of SE approach and it is meant to reduce the complexity in a project, it is essential to be highlighted during the interviewees too. It is interesting to know if decomposition is understood well and if it has positive effect on the project or not and why. This set is also related to systems and sub systems in a project. The interviewees are expected to have their opinion about dividing the problem and the project into separate (sub)systems and how they experience this.

SET 7: Decomposition, interfaces sub systems, different disciplines

50. Do you use decomposition technics during design process?
51. Does the decomposition fit in the total system of design process? Has the correct decomposition been used?
52. How are the interfaces managed?
53. How is the collaboration between different disciplines?
54. During the design phase, is the main or sub systems considered as the target (focus point)?
55. Is it possible to focus on the total system and why?

In this set of questions it is also going to be asked how the interfaces between the difference phase and the various disciplines are managed and whether the decomposition contributes to that.

8.1.8 Management and the bigger picture

This set of questions are managerial in the sense that the interviewees can give a general overview regarding SE according to their own experiences and insights.

SET 8: Managerial and Insight

56. Do you see SE as an explicit method? And does it work well in one shot?
 57. Do you think that the goals (efficiency, effectiveness, structures etc.) of SE have been achieved so far?
 58. Do you see potentials in using SE for the design process/total process?
 59. Are there any parts in the (design) process which could be improved? Do you see any shortcoming when using SE?

In the hypothesis of this research it was assumed that SE is an explicit approach and that it enables the project to be successful in one shot. These need to be cleared up in the practical sense and to see if it is true and how it is experienced.

The technical interviewees are able to tell what they see during the analysis and design phases and what the shortcomings are when using SE while the managers see the frameworks, the bigger picture and the potentials of using SE in the future. When both of these experiences and opinions are combined, a useful image can be created to see what the deficiencies of SE are, how they can be solved, how SE can contribute in the infrastructure projects and does SE fit in the construction (infrastructure) project and if not then why?

8.2 Process of Interviewing

With the theory and background information on SE in mind, a list of questions was composed for the interviews. (See Appendix, Interview Questions)

During the interviews it seemed that some questions were not relevant. Even though, they were put on the list to keep the conversation flowing and getting more information by discussing on a topic. If any of the interviewees could not answer a particular set of questions it was because they were not involved in that specific phase or they had no relevant insight in that part.

Nevertheless, some of the interviewees (who were not involved in the design phase) were only able to give general answers and how SE helped them in a project or what the added value of SE could have been there.

To get more insight in the implementation process other disciplines within civil engineering were interviewed as well. These were Real Estate & Housing, Water constructions, Rail constructions and NACO which focuses on construction of airports.

8.3 Process Case Studies

For case studies, two projects (Four-bridges and Expanding A2-Hooggelegen) have been selected in consult with the supervisors to investigate the application of SE a bit further in real projects. By this way more details can be given from an independent perspective. One can take a look in different ways into a project and it speaks for itself that after a project is finished still many different opinions can be given in regard to success/failure of that project.

In this research the phases, as given in the SE theory, were checked whether they have been used properly and to what extent in every of these two projects. After that one can see what kind of influence SE had on the projects and whether other factors played a role too during the project. The case study is done by looking into project documents and through extra session with the project leaders of these two projects.

8.4 Results of the Interviews

In this part the results from the interviews are presented. The complete answers from all interviews are available in the appendices. The answers of the interviews are used to make it clear what the condition of SE in practice is, how it is being implemented and the maturity process is going on and eventually to answer the research questions. Also out of these interviews remarks are subtracted which make it easier to see which shortcomings of SE have been noticed by these (project) managers along with the improvements that have been suggested.

In this section each set of questions will be considered separately and the main issues are addressed. If it happens that a result seems remarkable then it will be highlighted and elaborated extra.

8.4.1 The introduction set and the knowledge of SE

Almost all of the interviewees (90%) believe they had sufficient information and courses or materials to understand and study the theory of SE (Figure 23).

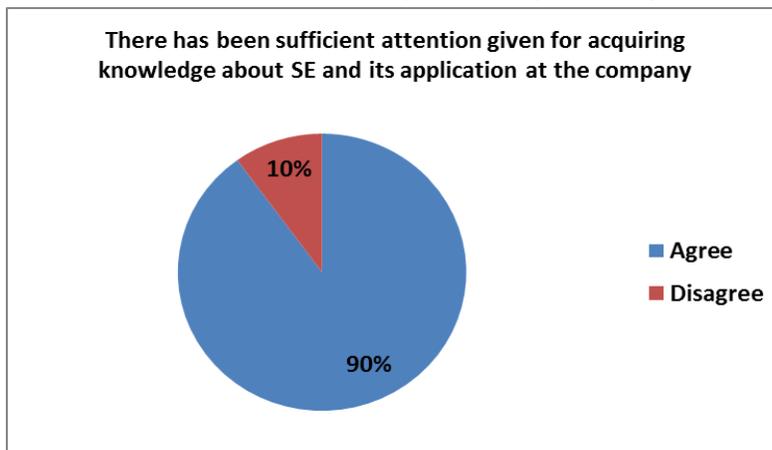


Figure 23: Chart of interview results 'Sufficient information about SE is obtained'

At the same time they all see the lack of experience in the practical sense by the designers during the design phase of the projects. This is mainly caused by the fact that there is tendency to still work and think traditionally and less explicit. This causes a slow maturing process of SE. They all agree that the more SE is used in the projects the more understanding and feeling they get as SE approach becomes familiar to them.

8.4.2 Analysis Phase

In the analysis phase the problem statements, projects goals, scope and requirements, stakeholders and risks analysis are investigated and composed. Here follow the results.

8.4.2.1 Part 1: Information and input

There is always a list of requirements made or it is already available in cases that the company is involved halfway the project. No separate list for wishes or possible boundary condition is composed since they are all included in the main list of requirements.

All the interviewees confirm that they are familiar with the term SMART and they try to get the requirements as SMART as possible; however the top-demands cannot be made SMART because they are abstract at that level. Such demands are then specified more in the sub-demands. A small group of the interviewees (20%) have experienced difficulties with clear understanding and application of SMART in practice (Figure 24). In such cases if it is possible, the requirements are specified further in deeper levels.

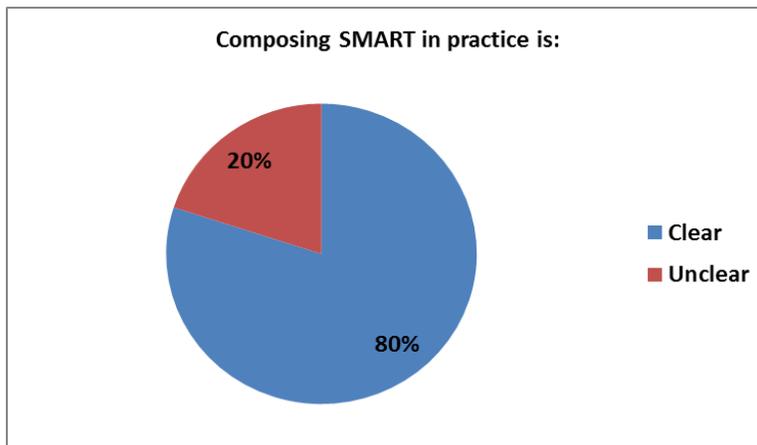


Figure 24: Chart of interview results 'SMART in practice'

The requirements are always double checked to see if they are complete and not contradicting one another. When they seem to be contradicting, then in consult with the client and experts they are reformulated and adjusted.

To the question whether there is a structure in the list of demands and wishes (all requirements), all answer positive. Most interviewees (90%) believe that when everything in a project is structured well and they are linked to one another, then things become traceable. Also the interface requirements and functional requirements are noticed easier and this reduces the chance that something is forgotten, hence they find such a structure very useful. A minority of 10% thinks that it is not a necessity to structure everything and they use structures because they has to (Figure 25).

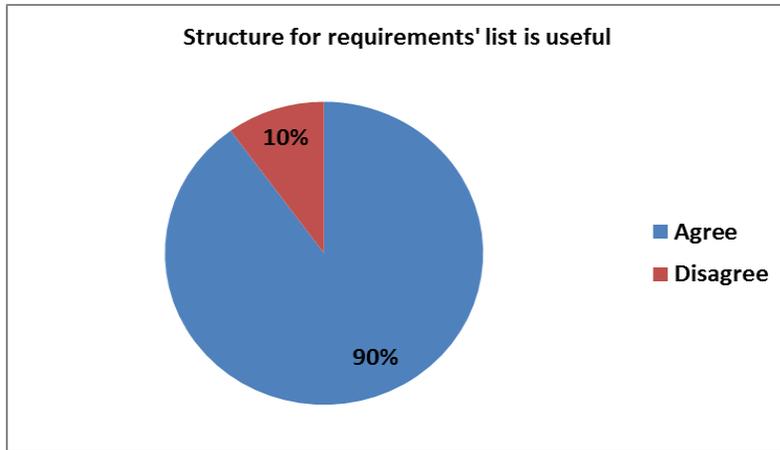


Figure 25: Chart of interview results 'A structure for requirements list is useful'

The interviewees notify that the problem definition of the project is explained in the quote of the client (Dutch: offerteaanvraag) but it needs to be formulated clearer since it is still abstract and implicit in a few cases (Figure 26). In these cases the problem definition matures and becomes clearer during the project later on when more information is obtained. The reason that it is less clear in the start of a project is due to complexity or the abstract formulation of the client's goal too.

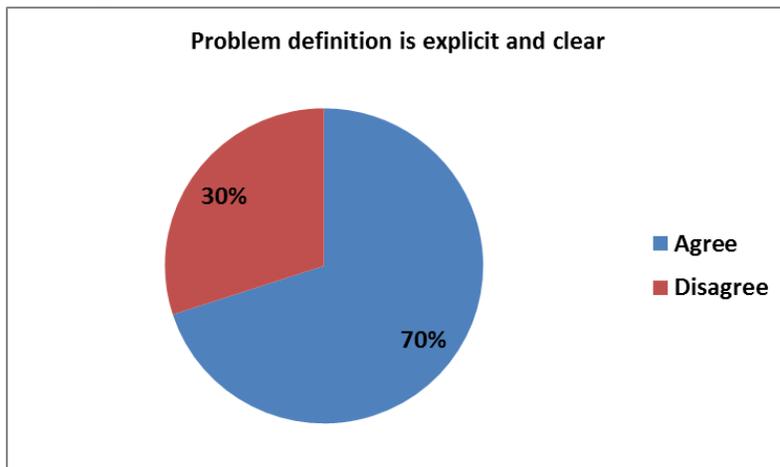


Figure 26: Chart of interview results " Problem definition is clear'

8.4.2.2 Part 2: Actions during analysis phase

Almost all interviewees (90%) mention that the requirements are double checked. Just 10 % say that it happens not always and if the client is satisfied with the requirements list and does not respond negatively then they start the designing phase (Figure 27).

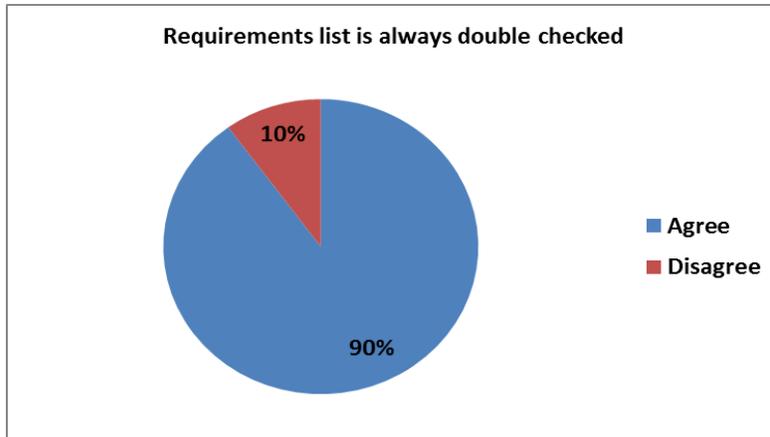


Figure 27: Chart of interview results 'Requirements list are double checked'

If there are conflicting or incomplete requirements then client and other experts are involved to find a solution. This prevents that the list consist errors which might cause difficulties for the next phase.

At this stage the given information is not always sufficient to start the design works and what is missing, is being requested from the client or experts (Figure 28).

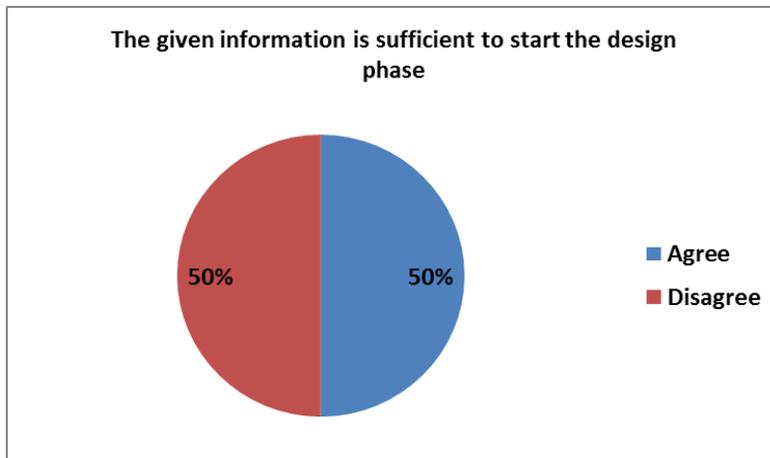


Figure 28: Chart of interview results 'The information is complete to start designing'

Not having enough information is caused by several reasons. In 20% of the projects it seemed that there was a huge amount of disorganized information and also there was a time pressure. In other 30% of such projects there were miscommunication and working implicitly which caused problems during the design phase. The more they get closer to the realization phase the more specific information are needed.

The required information is usually obtained from the client but also from expertise of engineers and other references if necessary.

The communication with the stakeholders and the clients happen through meetings, emails, phone calls, reports or with the i-Room.

When important decisions are going to be made or something needs to be validated then the client is informed.

The link between the requirements and the stakeholders is usually known (Figure 29). In cases that the links are not clear, there was no stakeholders analysis performed in the project.

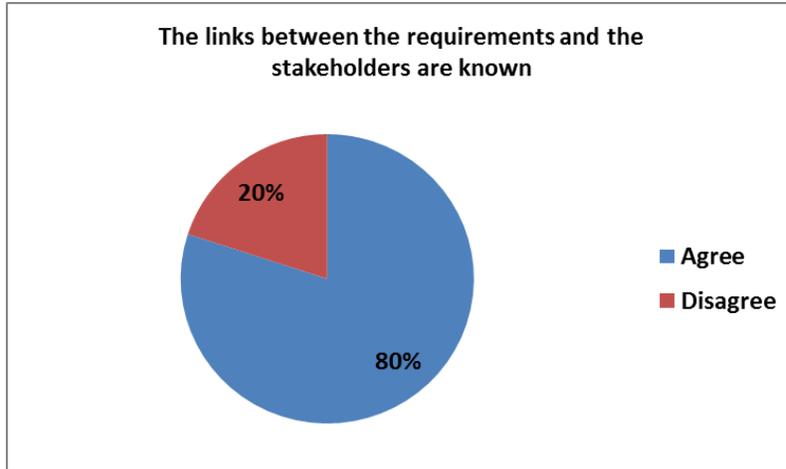


Figure 29: Chart of interview results 'there are links between requirements and stakeholders'

In most cases a general stakeholder analysis is made but not a detailed one. Project managers know who are involved and when it is necessary to know then the rest of the team is informed about the new stakeholders. It seems that not all stakeholders are involved usually. Those who possess less power and influence on the project, they are either forgotten or just ignored. The focus is more on requirements and less on stakeholders' analysis. But the involvement of stakeholders depends on the form of contracts and the project scale as well as client wishes. In an alliance there is better communication and since there is trust, everything goes smoother. Requirements are connected however the reason why a particular stakeholder has such a demand/wish is less clear or even not known at all. The requirements are allocated to the design objects in all projects.

The formats for stakeholders' analysis of DHV were satisfying (see Example Stakeholder Analysis in Appendix). It would be an advantage if the main requirements of each stakeholder are recorded in the same format as well.

A risk analysis is always carried out in every project but only in 30% of the cases it was not used throughout the entire project (Figure 30). That is because these projects were not complex neither large of size and the main risks were in engineers' minds' i.e. implicit. Usually the responsible person (Risk manager) updates and keeps other team members informed when necessary or relevant actions need to be performed.

The formats for Risk matrix at DHV were made very well and no serious adjustments are necessary.

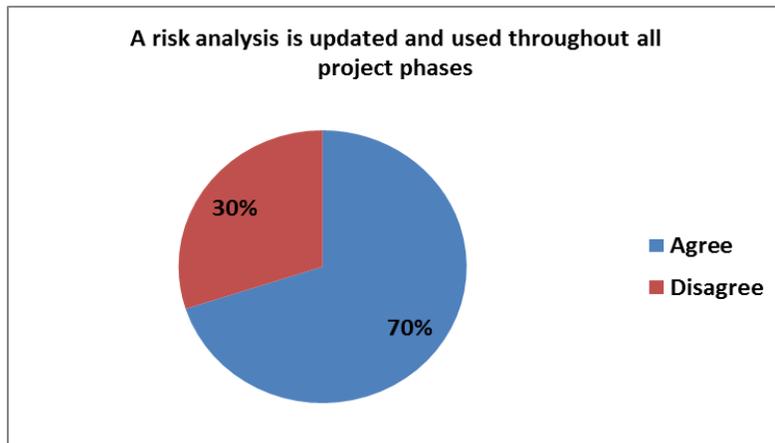


Figure 30: Chart of interview results 'Risk analysis is always used during the project'

The tools that are used are usually Relatics (as a database), Access and Excel. These tools are easy to use and new information can quickly be added or altered. There are courses for those who have to work with Relatics and inside the company there are employees who prefer Excel for the projects that are smaller or mid-size.

The outputs of this phase are at least a list of requirements, risk analysis, SE structures (functional) and sketches.

8.4.3 Synthesis Phase

The data and information from analysis phase are usually complete and sufficient to start the design works (Figure 31). Only 20 % of the interviewees disagree and that is because at the start of a project some data are based on assumptions since useful references were missing. In such cases, before the design phase starts, the client or consultants are informed and with their opinions the missing information becomes known.

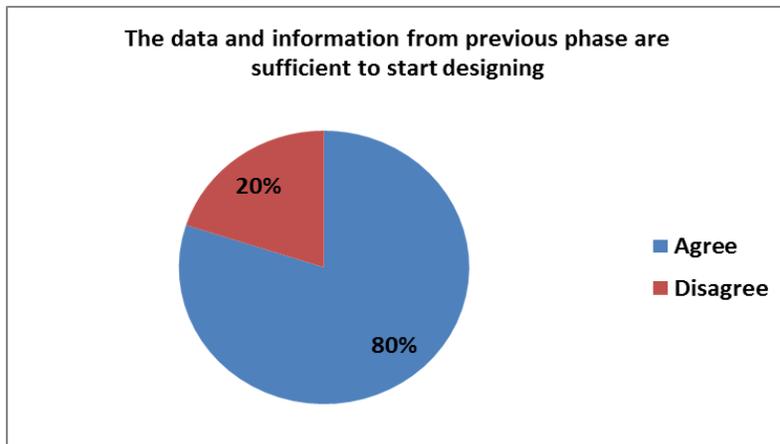


Figure 31: Chart of interview results 'Data from analysis phase are sufficient for the design phase'

The alternatives are developed during the design phase. However, there are also sketches or even initial concepts are made at the end of analysis phase if the client requests and wants to have more influence in the early phases.

The requirements' list is used as the input of the design phase. How these requirements (demands and wishes) are used during the design phase is interesting (Figure 32). The majority (70%) says that the designers look into the requirements list and then starts to design. In 30% of the cases it happens implicit which is based on previous experience, instinct, and what the designers have in mind for the solutions of a problem. In such projects, only the main requirements are considered and the details (usually the wishes) are taken less into account. Although long lists of requirements are made in many projects, the designers do not see the necessity to read every single requirement before designing except the major ones. During the design phase more or different requirements might come up and these should be added to the list which might mean alteration in the design too.

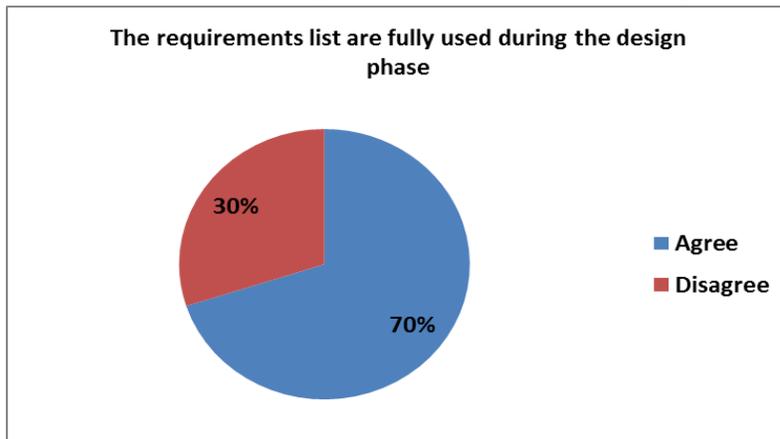


Figure 32: Chart of the interview results 'all the requirements are used during the design phase'

When a validation is needed or in case of consulting then the client is informed. The client's involvement decreases as the project is in the later stages unless the client requires having more influence on the choices and the decisions in the project.

There are many decisions made during the design phase and these are done internally by the projects team (see the Evaluation section). The small choices are based on experience and not explicit with underpinned arguments.

The outputs at the end of synthesis phase are at least the design products such as specified drawings and calculations, a complete list of requirements, updated risk matrix with the verification and validation matrix.

8.4.4 Evaluation of the design products

It is interesting to know how evaluation takes place in these projects as it is an integral part of SE approach. There is basically sufficient information and data available to evaluate the design. During the design phase it is important to use trade-offs when taking decisions or choosing between alternatives. It seems that trade-offs are not used in every project properly. The majority of the interviewees notify that either no trade-offs take place at all or very limited and implicitly.

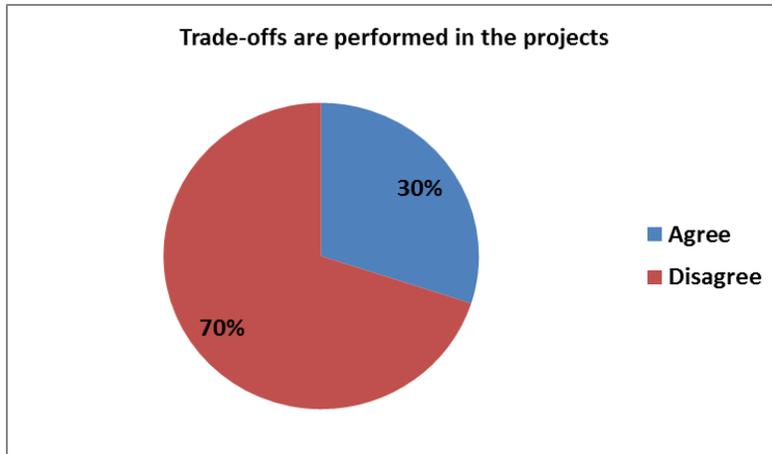


Figure 33: Chart of interview results 'trade-offs are used in every project'

This is because the designers are still used to the traditional way in which the expertise and instincts of the engineers are used the most. These engineers do not feel comfortable to make trade-offs for every decision because they do have sufficient experience to take right decisions they believe. When a decision or choices are made, they present it to the client and if things do not seem satisfactory then alterations occur. The most important thing is that the products should meet the requirements. Even in cases where trade-offs are used, the criteria and the scores are based on past experience and instinct of the engineers and projects leaders so decisions and choices might happen biased and less objective as well.

Also sometimes because dominant clients such as RWS have already taken many decisions beforehand or they want to have more influence on the products, then trade-offs do not seem necessary anymore. This leaves less room for the designers to go beyond their limits since they are not motivated when everything is predetermined. But this process is changing as the application of SE and integrated contracts grow.

Currently, the understanding and applying trade-offs in the projects is not sufficient. As for the contractors, often the cheapest alternatives (lowest costs) are chosen due to their goal to make as much profit as possible. Making trade-offs and knowing why and when a decision was made are very preferable and need to be done in order to make the process more explicit.

If trade-off is performed then Excel is used as the main tool because it is easy to use and gives a large overview of the scores and alternatives at once.

For a comprehensive example of trade-off matrix see Example TOM in Appendix.

8.4.5 Verifications and Validations

The designs are supposed to be checked if they meet all the requirements otherwise the client will not accept them. Verification was already mentioned in the previous section. It happens internally by the project members to make sure that the designs meet all the requirements. The subjective and abstract requirements are assumed and the experts are consulted for this as well. It is always required to present and demonstrate design performance for the client.

Validation is performed by presenting the products or the final outputs to the client and there is no special method for validation. If the client is satisfied and does not request for alteration,

then the product has been approved and thus validated. It is up to the client if more validations, during or after each phase, need to be occur.

Validation is done by showing 2-D or 3-D models, videos, presentations and reports to the client and i-Room²¹ helps there a lot.

For a comprehensive verification & validation format see Example in the Appendix. (See Example of Requirements Analysis in the Appendix).

8.4.6 Top-down structure and revisions

The design procedures happen for 80% top-down and everyone agrees that it is possible to do all the work with top-down approach. The 20% still work bottom-up which is traditionally and easier in practice. That is also when the details are known by expertise and past experiences but they need to be put in the bigger picture (system); so bottom-up approach is a logic choice then. Changes and alterations in the designs happen occasionally when the client comes up with new requirements or if he requests revision in the design during validation or consulting moments. It also occurs if some of the requirements were initially assumed and needed to be corrected later on. The consequences of alteration and revisions are delays and frustrations but also adjustments in the interfaces or the objects that are linked to the altered object.

It is common in all projects to go through several design cycles when designing one phase.

8.4.7 Decomposition, interfaces, sub systems

All of the interviewees are familiar with the decomposition technics and they have used these in the projects as well. They are not sure if decomposition is useful for the design phase. It does structure the requirements and the problem. But since there is no validation for decomposition figures, the interviewees do not consider these as very essential for the design phase because no one exactly knows which decompositions are flawless. Also if the designs are split up many times places then a lot of interfaces are created. This makes the project becomes less manageable and the overview is particularly lost in large projects.

In all projects there are responsible people who keep the interfaces in mind and take them into account. The management of interfaces seems to be tackled differently in every project (Figure 34). In most cases (70%) everything was performed implicitly and things were done with previous experiences. This sometimes caused missing interface requirements or a separate matrix in which the interface aspects are mentioned.

²¹ Integration-Room (i-Room) is referred to a tool which is used by DHV for the Virtual Design & Construction (VDC) concept. At this room Building Information Modeling (BIM) methods are used to get simulations for the best design and an integral process is aimed before the design phases starts.

Hereby the risks mentioned and client's satisfaction is increased (verification & validation). In the room there are large screens in which the situation of the problem is shown in 2-D or 3-D, risks are analyzed and the ideas are written down or drawn immediately (explicit) while people from different disciplines are present and other stakeholders can be invited as well. This improves intercommunication within a company between different disciplines but also with other stakeholders outside the company to inform and involve them in the project as well.

The "i-Room" can also be used for verification and validation steps whereby drawings, videos, risk matrices etc. can be presented and checked/approved by the client/project managers/designers.

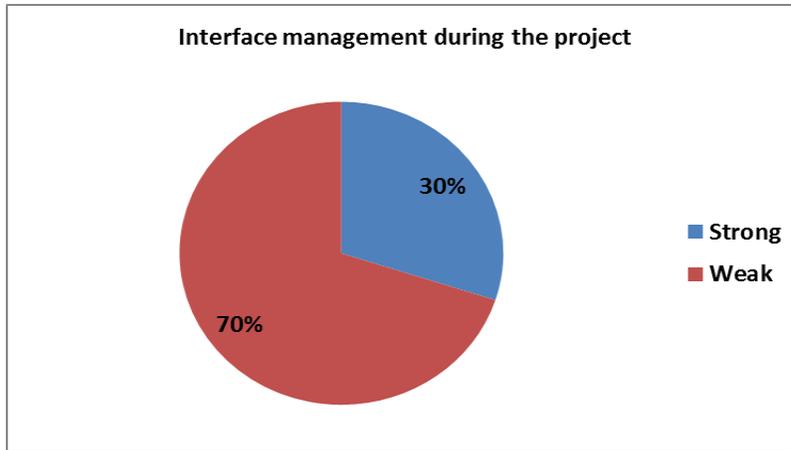


Figure 34: Chart of interview results 'interface management in projects'

An interface manager has a key role especially in larger and complex projects. He/she needs to consult the project team and together with everyone, identify the interface risks/requirements, discuss and recognize these and then getting agreed upon actions with the team members. Therefore such a person should have a lot of experience as well as knowledge of different disciplines. A strong interface management contributes to better collaboration between different disciplines in a project too.

During the design phase the focus is particularly on the sub systems but everyone agrees that it is also possible to focus on the total systems as well. In larger and complex projects it is though to focus on the total system because of the large size and many different disciplines that are involved in the project. In such large projects a huge amount of information is need to be discussed and considered.

8.4.8 Managerial and potentials of SE

All interviewees agree that SE is an explicit approach when it is applied in the project. SE does not cause a project to become a success in just one shot. It only structures and make every step traceable back to the initial requirements. Also the purpose of stakeholders and the links between these and the objects become clear too. That could be the reason that in large and complex projects, SE is useful for the analysis and the design phase along with the verification and validation steps. In that sense some goals (efficiency, effectiveness, structuring, explicit etc.) of SE have been partly achieved on the condition that SE is applied and understood correctly. It is not proven by underpinned argument that SE contributes to efficiency and more effectiveness. Everyone agrees that due to better structuring of the project and explicit work, the probability of risks and mistakes decreases and this could be considered as more efficiency in a project; though this probability cannot be calculated objectively.

In regard to potentials of SE, many different answers were given. All interviewees are of the opinion that SE has potentials and it can be useful. With explicit work and trade-offs, the products can be approved easier and that makes validation better organized and underpinned with clear arguments. Also the validations lead to a product delivery which was meant by the client. SE is not only for the design phase but also for the total project life cycle.

When it comes to the shortcoming or deficiencies of SE, the interviewees do not mention a particular part as a shortcoming. If SE could be flexible in the sense that a particular step of SE could be used in a particular project and not every single step of it, then it would have been more interesting to use. Hence, there has to be a balance which makes sure that not 'too much' but also not 'too little' of the SE approach is being used. In smaller project, SE is experienced as 'too much work' which is considered as not necessary at all but in large projects, SE contributes to explicitly and structuring the project.

According to all interviewees, it is both the lack of knowledge and understanding as well as how to apply SE correctly which should be improved and not the SE approach itself. Hence it is a matter of time and maturity of SE within the construction industry until it becomes a common approach. Therefore, more examples and references of 'correct' implementation and successful application of SE in the construction (infra) projects need to be available and accessible to everyone on the market.

8.5 Results of the Case Studies

For each case nine steps and questions are discussed. The steps are from the processes of SE and then how they were applied during the project and finally what the role of the contract type could be. At the end a brief conclusion for each case is given.

8.5.1 Case 1, The 4 Bridges

Provincie Noord-Holland (PNH, the client) planned replacing four fixed bridges (Mielbrug, Hemmerbrug, Groetpolderbrug and Lutjewinkelbrug) for the municipality of Niedorp in an E&C contract. The older bridges were installed for a long period and new ones were required. The client did not want to have different type of bridges and wanted to keep the environment as it was and the new bridges had to fit in the current environment.

List of Requirements

PNH already had made a list of requirements ready and things started it traditionally without involving SE as a tool. The client wanted the new bridges to be like previous ones so many of the requirements and boundary conditions were already fixed. DHV had to convert and adjust those requirements according to the SE structure.

Stakeholder analysis

There was no explicit stakeholder analysis made but it was attuned with the client and in consult with it in an implicit way. Number of stakeholders was limited and known to others but not all stakeholders were informed.

Risk analysis

A risk analysis was made and twice updated as well. But the project was not navigated based on this risks analysis.

The project wasn't very large and no big issues were involved since the bridges were in the countryside and detours were needed for the traffic.

<p>Design process</p> <p>The input came in from stakeholders with alterations from the Hoogheemraadschap (governmental water management organization) and later it seemed that not all stakeholders were consulted about the detours. A delay was occurred due to additional demands from Hoogheemraadschap regarding the weir. This caused further investigation and sheet pilings needed to be added to the design as well.</p> <p>Environmental requirements were difficult to be put in the contract in the early stages because during the design stage more issues became clear.</p>
<p>Trade-offs</p> <p>Tradeoffs were not performed explicitly according to SE but more on traditional way with intuition and experiences from the experts. This had no serious influence on the projects and its process in this particular case.</p> <p>Moreover, the type of the bridges were already fixed and chosen by the client.</p>
<p>Verification & Validation</p> <p>No explicit verification was occurred with all requirements and their integration in the design. This had consequences and one of the bridges did not meet all the requirements and the client complained about this.</p> <p>It seems that there was a high probability that the mistake would have been noticed on time if a good and explicit verification was made. Also some new requirements were not added to the list. Validation was done well but with the client and it went less smooth.</p>
<p>Interfaces</p> <p>There was no separate interface management occurred but the interfaces were mentioned in the documents while not mentioning how to manage them. Interface management happened implicit and not too deep either.</p>
<p>SE as tool</p> <p>From the moment that SE was used there was more structure in the processes and more explicit but no verification according to SE was done.</p>
<p>Type of contract</p> <p>It was E&C contract but not all elements of SE were used because no necessity for that was noticed. In large contract and contract which include maintenance as well, is SE more suitable.</p>

In case 1, using SE as a tool started later in the project. The analysis phase was for the most part already done and it just needed to be translated into technical requirements. This interface could be the cause of forgotten some requirements which later was noticed by the client.

Furthermore:

- The project was not complex and no high risks were involved. Using SE was new and team members learned a lot from that.
- SE made the project getting more explicit and structured but eventually mistakes did occur. This can be thanks to the fact that SE was not used from the beginning and not all requirements were linked to the stakeholders.
- The project like all other cases could not be made well in one shot and it's not a surprise either.

- The size of the project was medium and since SE was not applied from the start it was less efficient.

However, it's very much possible that if SE was not applied at all, more mistakes could occur. Therefore, generally speaking, SE has contributed positively in that sense.

8.5.2 Case 2, Expanding A2-Hooggelegen

The area around Utrecht city was suffering from huge traffic jams and expanding the roads was the best option from 2x2 lanes to 2x5 and it reduced the traffic jam very much. The project was very large and executed in the form of Alliance which was experienced very positive and successful.

List of Requirements

There was a database for all the analysis elements and in this project very much attention was paid to composing requirements and converting them to technical and functional requirements. Also separate requirements for the process and managements were made. Clear problem definitions were made and good formulation of scope and project's goals. Level 3²² of maturity levels was achieved.

Stakeholder analysis

In this project a complete stakeholder analysis was made. All the stakeholders were mentioned and their influence, position and interests and their requirements were traceable. Due to the form of the contract (alliance) the communication between main stakeholders went very smooth and with trust. Other stakeholders too were informed and involved in the project so far it was needed. An environment manager was appointed to manage these communications better.

Risk analysis

The project had to be finish in a short period of time so there was high time pressure and the environment had a high load of traffics on the roads and this project was very large and complex. The RAMS-method was used in the risk analysis and during the project the risk database was updated regularly and engaged in the project as well. Also during trade-off the risks were involved to make them best choices. Not only a risk analysis was made but also risk management was done throughout the project

Design process

The design phase occurred very much according to the theory and steps of SE. From the draft design to final design and realization design, each one with design reviews and baselines to make sure all the requirements are integrated. Specific attention was given to Technical clusters in a phasing management to create input for the solutions.

²² To depict the development possibilities, the so-called CMMI-model (Capability Maturity Model Integration) was adopted which was originally made by Carnegie Mellon Software Engineering Institute (www.sei.cmu.edu/cmmi/). The model describes five levels and it's been tested in practice ad a natural development model for implementation of process changing like implementation of SE. The aim of RWS and ProRail was to achieve level three of maturity in the Dutch construction industry in all infrastructure projects within five years after implementing SE. But it seems that this development is going slower than expected.

<p>Trade-offs</p> <p>Trade-offs were carried out in the design phases while taking many criteria (multi criteria analysis) including risks into account. This to make sure that the solutions are underpinned and weighted against each other.</p>
<p>Verification & Validation</p> <p>Separate Verification and Validation methods were agreed upon and made explicit. During the project they have been used and with positive and successful results as well.</p>
<p>Interfaces</p> <p>Interface management was carried out and updated regularly in which design leaders and environment managers were involved. Regular meeting were hold that things are not forgotten and taken into account. The interfaces are mentioned and plans and promises were made and added to the verification plans as well.</p>
<p>SE as tool</p> <p>The project was carried out entirely with SE as the main tool. The theory from ISO 15288 was very much involved in both the design and the project management processes. It seems that SE was used very successful and implemented well and a higher maturity level has been achieved compared to previous projects.</p>
<p>Type of contract</p> <p>The Alliance was an innovative form and very young in Netherlands. The parties involved experienced it very positive and it ended with good results. Integrated contracts and SE seems to be a good combination.</p>

In case 2 using SE as a tool was experienced very positive. Due to complexity of the projects, SE was a suitable and effective tool to finish successfully and without mistakes that could harm the project in terms of costs, time or quality. Furthermore:

- SE was applied very much according to theory and from the start until the end of the project.
- An important factor that probably have contribute to this success was also the form of the contract (Alliance) which made communication easier and more trust was felt between stakeholders and team members.
- The structures way and making everything explicit from the start along with underpinned trade-offs made this case very attractive to be used as successful examples. Here one can clearly see the benefits of SE since the project was complex and very large.
- Many stakeholders were involved and a lot of requirements were there and different parties were taking part in this case which might have caused chaos and miscommunications.
- SE contributed a lot in this project and one can link this success due to the large size of the project and the trust between the team members.

Chapter 9. Final Discussion on Systems Engineering

In this chapter the finding from the previous chapters are discussed critically. This is a final reflection as well as comparing the theory of SE with the results from the practical part. In this chapter the deficiencies of SE are being discussed before answering the main and sub questions in the conclusion and making recommendations afterwards.

- Using SE is experienced and considered an explicit way which helps the team members but also the client to trace the requirements in the designs. But also to find out why, how and when a choice was made, something was altered, verified or validated and for who (stakeholder) that choice was meant. With SE the scope of a project and problems can be put clearer by making it structured and explicit while accessible to other members or stakeholders. SE contributes to efficiency if it is applied in larger and complex projects correctly. Especially in the projects that management and maintenance are also included in the contract (e.g. DBFM) and this makes the project last longer or become complex in many cases.
- SE was developed in the manufacturing and aviation industry and therein it fits the best because in those industries the requirements are fixed after a trial and error period during making a prototype for the project. And based on this prototype they produce massively later on.
After SE was introduced in the construction industry (infrastructure projects) it clashed somehow with the traditional approach in which no functional requirements were used. Instead, make use of ones intuition to find a solution was very casual and the procedure was less explicit. RWS wanted to increase efficiency within construction projects while at the same time aiming to have higher effectiveness i.e. better products.
The uniqueness of the construction projects makes it more difficult to use a tool that was meant for a different industry.
It does not mean that using SE is impossible in the construction industry.
It needs maturity and familiarity within this industry and the engineers and project managers must be educated and get proper understanding of what SE is and how it should be applied in practice and not only in theory. That is achievable if more projects are carried out while using SE and learning from previous experiences in the projects and passing this to the new ones.
- One thing that is very true and all agree upon is that SE makes it possible to get things explicit and treatable in the projects. This has an important condition as well and that is: to use SE correctly and apply it fully in all steps of a project.
Large and complex project are better domains to use SE because such projects can fail quicker even by experienced managers. Complex projects contain higher risks and many different requirements from different stakeholders that should be taken into account as

well as many interfaces and dynamic environment are involved. These should be structured and organized very well to prevent mistakes and failure and reduce the risks as much as possible.

In small projects SE is not efficient because it requires extra work for making everything explicit from collecting information to communications and choice made or solutions along with the justification for each part.

The current implementation of SE is going slower than it was initially supposed to. The increase of successful projects and the familiarity with SE (e.g. by encouragement from the management) will contribute to acceptance of SE and faster maturity of it within the construction industry. It would then become a common tool to be used in all complex and large projects only if it shows concrete results regarding efficiency and better products.

- Not all the initial goals of applying SE in the construction project are achieved so far. The process still needs to be matured and for that goal more time and experience are required. The client expects that the solution makers can convince him and justify their designs with underpinned arguments and not just based on intuitions. In other disciplines than Infrastructure, for example Real Estate & Housing (Buildings), Water construction and Rail, SE is even less mature and in there they look into the developments from Infrastructure departments which are far ahead.
- Currently for many designers using SE is experienced as an extra load with no immediate and proven results. On the other hand the managers are more enthusiastic about SE and see potentials for it in the future as well. Successful examples needs to be shown to everyone to convince them that SE contributes but also if SE is not used, more mistakes could be made because things such as risks and interface requirements could be forgotten easier when the project is complex and large.
- Right now the trade-offs are not performed exactly the way it is expected by SE theory and these happen usually still implicit by expert judgments which could be biased in some cases. Also the connection between requirements and the corresponding stakeholders is usually not explicit in most projects. The reason and the goal of requirements should be made crystal clear to see if they make sense and what other alternatives exist for those requirements, particularly when some of the requirements are in contradiction with one another or formulated in an abstract way. If possible, standardization in some aspects of trade-off would make it easier. That is because it is sometimes difficult to give objective scores and unbiased weights to the criteria.

- Interfaces need to be managed better in the sense of making the interface requirements explicit and known to all team members from different disciplines. Also if alterations are requested by the client, flexibility is preferred and SE should allow that. Because everything is explicit, the consequences of such a change can be seen quicker and this can be shown to the client immediately.
- SE seems to contribute to the total life-cycle but when it is applied only during the design phase then the efficiency goes down. That is because SE has been used incomplete and not throughout the entire project cycle. Designing top-down is possible but takes longer and designers should get used to this way yet. It needs to become a habit and fit in within organizations to the extent that they know when and how and to which extent SE should be applied in every project. Other departments like Real Estate and Housing, Water Constructions are lagging far behind, compared to Infrastructure, in regard to implementing and using SE in their projects.
- If the project is not managed well then the specifications can go very deep in details and that causes large books of databases which are only made to have them available and not to review them per page. The designer should be able to have a good overview of the project. SE should be applied from the beginning until the end of a project and not just in one phase. This will increase the efficiency and become an ineffective tool in the projects eventually. The level of depth in making specifications depends on what the client wants and how much influence he prefers to have on the project. The more influence a client wants to have the more he needs to specify and go deeper in the specifications before handing it over to the market (i.e. contractor). This would mean that the market has then less room to make other alternatives and solutions.
- Using virtual tools like i-Room, videos and advanced pictures can also be seen and added to the approach of SE when it comes to validation, verification and communication between stakeholders and even the team members internally.

9.1 Comparison the Practice with the Theory

With these results and the findings from the theory it becomes obvious that the deficiencies and the compatibility of SE within the construction industry could already be foreseen.

The fragmented nature of construction industry and contractual barrier between the phases make it harder in the practice when using SE. This is mainly caused because the different parties do not trust one another unlike the manufacturing industry where a large company designs and realizes the products itself too.

The fact that SE makes the processes explicit and traceable was noticed in the literature study and it is been confirmed in the practice as well.

Whether SE approach makes infrastructure projects more efficient and having effective results, is still an issue that people can discuss about because there are no underpinned proofs available. In complex and large projects it seems that SE helps more but in smaller projects it could even be extra work and thus less efficient.

Not every step from the theory is being used or practiced although it is supposed to when effective results are desired. There is more time needed to let SE become a habit for every person in a project and to become matured in the construction industry.

If the stakeholders analysis is done correctly, one can easily trace which stakeholders are involved and why. This is possible when the demands and wishes of each stakeholder are made explicit and converted into (functional) requirements. After that, each requirement is linked to a stakeholder and if SE has been applied well then one should even know why a stakeholder has such a demand or wish.

Also the risks and verification and validation methods will be known along with interfaces and the promises/actions which are made in regard to them. All of these are made explicit and traceable if SE has been implemented according to the theory.

Unlike automotive and aviation industries where a prototype is made beforehand and the requirements become fixed, in the construction industry the projects are unique and different stakeholders with different requirements and various environments and boundary conditions are involved. It seems that finishing a project with no complications at all is not possible in the construction industry; especially when the projects are large and more complex (i.e. more stakeholders, more laws, and more risks etc.) with dynamic environments every time.

SE is just a tool to help that purpose and it could be very beneficial in complex projects to the extent that the processes are done in a structured way and everything is explicit which would reduce the probabilities of failures and mistakes.

If all of the clients' requirements are met while being in good communication with them during different phases to make sure the designs are really the way they prefer and require, then much less surprises will appear later.

It is possible that although SE was used in a project but the communications went wrong somewhere else and the tensions between the stakeholders caused loss of trust among the parties. And this would lead to more troubles in the project which results in failures while this has nothing to do with SE. Vice versa, other aspects can contribute to the success of a project too with or without using SE. For example when there is much trust, smooth communication and stakeholders understand each other while no serious risks are involved either. At the end, a good product was delivered within the budget and time limits and using SE was not necessarily 'the cause' of this success.

Finally, SE should be understood better (not only the theory) and practiced more until it gets mature and people feel at ease when using SE. Making everything explicit and finding arguments for the choices made through trade-offs, need extra time but eventually those contribute a lot in the total process of a project.

Although a different approach without using SE in a project can be successful too but the elements of SE will be recognizable in that approach as well.

Previously, designs were solution-oriented (i.e. the designers would jump immediately on a solution made by his intuition and experience) while now it is more functional-oriented (i.e. the problem gets more attention, e.g. which functions are demanded and desired by the client before thinking of a solution/design). And since designing is choosing, this new approach with Integrated Contracts plus SE as a tool is very suitable to that demand.

However, SE and the form of a contract should be seen as two separate things. The question should be: What does the client want? And based on these demands and wishes, a suitable form of a contract should be chosen while SE is a tool to help the project to a success and manage the complexity.

If RWS or other clients did not require the implementation of SE, probably other tools or just the traditional approach were being considered in the current Dutch construction industry.

10. Conclusions

Based on the results of this research, the following conclusions are made in the form of answers to the main and sub research questions. Also the hypothesis of this researched is proved.

Sub questions 1: What were the initial goals of applying systems engineering in the construction industry?

Answer:

The initial goals of applying SE were to reduce complexity in engineering projects.

In the *literature study* it was mentioned that the SE approach was introduced by ProRail and RWS in the infrastructure projects in the Netherlands. SE was meant to increase efficiency in large and complex projects with more successful results (higher effectiveness). That is being aimed by giving structure to complex projects through decomposing the problem and requirements, making every step explicit and considering all risks and stakeholders requirements timely which eventually would reduce the failure costs and deliver better products.

Sub question 2: Considering the current application of systems engineering approach within the Dutch construction industry, to which extent have the initial goals of SE been achieved?

Answer:

In this research it was discussed that in the current state of Dutch construction industry, the initial goals of implementing SE have not been achieved entirely. Also previous to this, it was mentioned that the construction industry is fragmented and the projects are the unique in dynamic environments.

The *interviewees* believe that SE only structures a project and it makes every step traceable back to the requirements and stakeholder as well as the links between them and the objects become explicit too. In that sense some of the initial goals (efficiency, effectiveness, structuring, explicit etc.) of SE have been partly achieved if SE is applied and understood correctly.

It is not proven by underpinned arguments that SE contributes to efficiency and more effectiveness. The *interviewees* agree that due to better structuring of the project and explicit work, the probability of risks and mistakes decreases and this could be considered as more efficiency in a project; though this probability cannot be calculated objectively.

Hence, the *interviewees* cannot prove that a success in practice of infrastructure projects is only due to using SE. Neither can they confirm that only because of application of SE, the efficiency has increased because this depends on many other factors too.

Sub question 3: How can the systems engineering approach get improved for application in the lifecycle of construction (infrastructure) projects?

Answer:

The *interviewees* believe that the SE approach itself does not have shortcomings. It is the lack of understanding by the project teams and partly because of the new area in which SE is being

implemented that cause unfamiliarity with SE or experiencing it as something extra by the designers.

They suggest practical ways to improve 'using' the SE approach in practice of infrastructure projects and those are:

- The requirements from the analysis phase should be linked to the stakeholders and it has to be known why they have these demands and wishes (stakeholders analysis). Also the stakeholders have to be more involved and their requirements need to be underpinned clearly.
- A risks analysis must be used more integrally; throughout the entire project and updated regularly.
- During the design phase, the team members are still focusing immediately on the solution and not as much on the problems and functional requirements. This should be more balanced and thinking from a problem or functional perspective takes time to become a habit.
- Trade-offs are necessary in complex projects while in smaller projects they are either not performed or done incorrectly. The designers should have underpinned arguments when making choices and taking decisions and justify these actions explicitly in every step. That can be done by making trade-offs which are integral parts of the SE approach.
- Verification takes place in many cases implicitly and this could cause a certain requirement to be forgotten which might lead to mistakes later on in the project.
- Interface management is performed very poor in most projects and this really needs to be improved by creating a separate list/matrix of requirements and boundary conditions for the interface aspects. Such a list should be accessible and known to every team member but also updating and recalling the interface issues to the designers frequently.

The main research question: What does the Systems Engineering approach contribute to efficiency and effectiveness in (complex) infrastructure projects?

Answers to the main research question

The SE approach is believed to be not understood entirely in the infrastructure projects.

The *interviewees* are of the opinion that SE structures the project and makes all steps explicit when it is understood well and applied correctly. That increases the traceability of the links between stakeholders and their requirements as well as the design objects. The risks are notified earlier and this reduces the chance of failures in the projects, they believe.

Moreover, the *interviewees* think that large and complex projects are a suitable domain for using SE while in smaller projects; SE is not efficient and creates unnecessary extra work.

Also they believe that in practice, SE still needs to mature within the construction industry and better be understood by both design engineers and by project managers in order to make the implementation of SE successful.

The results from the interviews have also clarified the hypothesis of this research, which consist of three parts.

Hypothesis: Systems Engineering is an explicit approach which causes success in one shot and the clients gets the optimal product which he wishes to have.

- Firstly, SE is indeed an approach that makes each step explicit if it is applied consistently and implemented throughout the project correctly. SE requires from us to make the process traceable and being structured and justifies the choices that are made. Hence, this part is proved to be true.
- Secondly, a project cannot be finished at once and that is due to the nature of the construction industry and its dynamic environment. Therefore, this is proved to be impossible.
- Thirdly, whether the client gets the optimal product that he/she desires is conditional because it depends on many aspects and different factors and the success is not just dependent on SE.

However, SE adds value in complex projects because it structures the entire project and it prevents the chance of failure through different tools such as risk analysis, stakeholder analysis, objective trade-offs and frequent interface management.

11. Recommendations

- A comprehensive stakeholder analysis contributes a lot to the success of a project and therefore such an analysis needs to be performed in every project very early and being updated when necessary. This also means that the demands and wishes of each stakeholder should be made explicit and the idea or reasons behind those requirements have to be known too. Involving stakeholders can be made easier by using the i-Room and inviting them over and presenting the problems while keeping the sessions interactive. This is done through explaining to them how and why a solution/idea works there better and referring back to the problem every time. The agreements and comments should be made explicit right there and to be used in the next step.
- Risk analysis in every project is inevitable and this should not be performed only for the sake of integrity but throughout the project while being updated (i.e. where the risks comes from and how to treat/transfer/tolerate/terminate risks) and taking those risks into account before each decision or choice is made.
Such a risks analysis should be made in the format of an easy accessible matrix for all the team members and not containing abstract information or large amount of data that overwhelms the designers.
- More attention must be given to the interfaces, the related requirements to them and their management by mentioning them explicitly and involving team members to the processes of managing interfaces. After these, solutions and actions should be made explicit and an interface manager has to be appointed to control these issues. This person has to look after the interfaces regularly and inform every one about their responsibility and make sure there is communication between different disciplines. Also the team members themselves have to be aware of at least the interfaces that are related to their own disciplines.
Visual session in the i-Rooms with all team members can be very useful and easier to remember later. This has to be done before designing and during the design phase as well.
- In all projects there must be explicit trade-offs to justify a solution/choice and the preference of an alternative above the others needs to be underpinned with arguments. This strengthens the reason behind a choice when presenting the results to the client. But also when changes are requested and things are going to be altered then the team members can find and trace everything quicker and easier.

- Verification and validation must be carried out in every project and more standard methods need to be in basic formats; how and when to verify and to validate.
Using the i-Room as a tool for validation is very effective and should be put in practice in all projects. That is because the i-Room integrates all disciplines into one whole and with interactive sessions from all disciplines, the major risks and obstacles are clarified to all team members and everyone gets an overview in different disciplines and aspects of the project.
- No large documents but more practical examples and standard formats need to be given to the designers and project managers to teach them about SE in practice. This has to be performed by using successful and satisfying examples from other projects to encourage team members in using SE for the entire project. This will also speed up the maturity level of using SE in the construction projects overall.
The project managers should oblige their team members to use SE if they want to increase the level of understanding and getting used to the new tool.
- SE should be used in large and complex projects from the start until the end of a project. In projects that also maintenance is attached (e.g. DBFM) SE is a useful tool because the whole life cycle is being considered.
SE should also be emerged with the design work and more integrated into the phases and not as a separate specialty on its own.
- ❖ Further studies are recommended and would be very beneficial on:
 - Applying QFD tool within the SE cycle during making list of requirements and using AHP for trade-off formats to get unbiased weights within the construction projects.
 - The tailoring process before implementing and using SE from different industries and how to tailor (transform) a new approach from other industries into construction projects before it is implemented.
 - Innovative tools in which a sketch of the situation and a problem would be given and the software can deliver outputs for minimal requirements, boundary conditions, risks, interface aspects, estimated costs and time visually in one overview.
 - How to tackle with the contractual barriers in the construction projects when using SE

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Appendix

List of Questions for Interviews

Introduction, projects involved and info about SE

1. Which project(s) have you been involved in which SE was applied?
2. What was your job in that particular project?
3. In which phase is this project right now?
4. Has there been enough attention given for acquiring knowledge about SE and its application, at the company?

Analysis Phase

Part I: Information and collecting data before starting a project

5. Is there a list for requirements (demands)?
6. Is there a list for wishes/preferences?
7. Are the requirements composed SMART?
8. Is there a structure in the list with demands and wishes?
9. Do you find this structure useful?
10. Is there a clear problem formulation?

Part II: Actions during analysis phase

11. Are the requirements double checked? (Conflicting, consistency, completeness, etc.)?
12. How is it handled with the conflicting, incomplete or critical requirements?
13. Is the given information sufficient to start the design works?
14. Through which way are the required information gained?
15. How does the communication occur with other actors in this phase?
16. In which way is the client involved in this phase?
17. Is there a link between the requirements and the stakeholders?
18. Are the requirements allocated to the design objects?
19. Has a risk analysis been performed before making further decisions?
20. Which tools are used during this phase?
21. What is the output and are there other documents produces in between?

Synthesis Phase

22. Is the information and data from the previous phase sufficient to generate design alternatives?
23. Are alternatives developed in each phase (concept design and final design)?
24. How are the requirements used during the design?
25. Is there a clear design scoop based on the available specification?
26. How is the client involved in this phase?
27. Are there interim decisions made for the design?
28. What kind of output is required?
29. Which output is generated but not required?
30. Are there any other documents generated in between?

Evaluation, Trade-off and its criteria

31. Is there sufficient information/data available for evaluation?
32. How is it made sure that the all evaluation criteria agree with the demand?
33. How are the subjective and non-measurable criteria taken into account?
34. Are the criteria considered in regard to usability , maintainability, feasibility, demolition and life cycle costs and how?
35. How do the criteria get a score, how are the alternatives valued?
36. Is there one evaluation moment or are there several moments in between as well?
37. How is the client involved in this phase?

Tradeoff tools

38. Are there certain evaluation methods used?
39. Is there special software used?
40. Is there any other tool used?

Verification &Validation

41. Is it required to demonstrate the design performance (to the client)?
42. Which actions are executed by a designer to demonstrate the incorporation of requirements in the design?
43. How are the subjective (biased) and hard- to- measure-requirements demonstrated?
44. How does the validation take place?

Top-down, bottom-up, changes in design and revisions

45. Do you go through all steps in every phase?
46. Are things designed in top-down or bottom-up way?
47. Is it possible to design top-down?
48. Are the design choices revised often? What are the cause and the effects of such revisions?
49. Do you go through several design cycles when designing one phase (preliminary or final design)?

Decomposition, interfaces sub systems, different disciplines

50. Do you use decomposition technics during design process?
51. Does the decomposition fit in the total system of design process? Has the correct decomposition been used?
52. How are the interfaces managed?
53. How is the collaboration between different disciplines?
54. During the design phase, is the main or sub systems considered as the target (focus point)?
55. Is it possible to focus on the total system and why?

Managerial and insight

56. Do you see SE as an explicit method? And does it work well in one shot?
57. Do you think that the goals (efficiency, effectiveness, structures etc.) of SE have been achieved so far?
58. Do you see potentials in using SE for the design process/total process?
59. Are there any parts in the (design) process which could be improved? Do you see any shortcoming when using SE?

Answers to the interviews (In Dutch and English)

On request the interviewees' names are not mentioned.

Note: Some interviewees could not answer every question and those question were skipped. Therefore the sequence of the answers is not always as the sequence of the list of the questions.

Short interview with Managers (answers to managerial questions)

Interview 1

It's been complicated to implement Systems Engineering because it was new and people and it's been costly.

1. Yes we can say that since SE is basically working systematically and recording things on paper while people could see what's there and what's been taken place.
Also the chance is bigger to produce the correct product in one shot since a lot of verification & validation should take place, however, in practice things can go wrong by avoiding V&V steps or not doing it accurately.
2. Not really due to the previous resistance when implementing SE and still the negative picture some people might have.
We started a bit incorrect when implementing SE. It came off as a heavy load on people's shoulders while SE is actually not difficult and it's a structures way of working, very logic constructed in fact. In 2006 we started to use Relatics as a tool for implementing SE and making specifications but it came off as a heavy method to many while it shouldn't be experiences as heavy. Employees were confused why they need to use such a 'complicated' way for normal projects because they were used to do it on their own way. This caused some fear ever since but slightly it's becoming familiar.
3. I'm not sure about the design process but in regard to total process yes I do see potential for SE. Because when things are written down explicitly, one can check the output of each step easier. I do believe that SE should become a standard method for everyone to be easier to use for all.
4. During communication things can change and it should be flexible to edit and adjust things when working with SE.
5. When a method tends to cost a lot and it seems that something went wrong in previous phases, new approaches become attractive. You want a way to be able to control the process and find out, in an easy way, where and why something went wrong. This to be able to avoid mistakes next time.
The list of requirements should be complete. If the demands and wishes are not explicit then you could get problems. In traditional way if a requirement is forgotten or missing then the designer improvises one based on his previous experiences while this can be mistake and not suitable for the current design. But when it's been discovered in the later phases, it'll be too late to return and correct this unsuitable requirement.

The level of understanding and knowledge amongst people in a company is not equal. If you ask ten people to define the FD (Final Design, in Dutch: DO), you'll get ten different answers while not everyone knows exactly which elements are included in the FD. This should be known to everybody but in practice it's not.

In the future I'd like to see that the Client and the Contractors use the same tools/software for implementing and using SE. This makes the interfaces to be more fluent and less miscommunications and thus more efficiency and effective.

Also, there should be milestones between each phase. This to make sure that everything is complete and included in the output which will be the input for the next stage.

In feasibility study are some specifications needed as well so we cannot have a plan without an amount of a basic level of specification at least. You need this to know which risks and uncertainties are involved in the project when you deliver it to the contractor. So if you stop earlier in the systems and sub-systems level then you don't know much about the risks and can't give good estimations. If more space is given to the contractor/market, then more risks need to be taken by that party.

Unless you want to build a road in the middle of a desert where it does not matter whether the road has noise barriers or not. But in a city it does matter how a road is going to be constructed and existence of noise barriers and its size do matter.

Interview 2

1. SE is wel expliciet maar gaat niet in een keer goed.
Het is meer vastleggen en daardoor heb je meer waarde. Het moet wel op een juiste en goede manier gedaan worden, d.w.z. eisen zo goed mogelijk door de OG worden beschreven en duidelijk gemaakt. Een ontwerper wil zo min mogelijk eisen zien om te kunnen ontwerpen terwijl de OG soms de eisen wil wijzigen.
2. De doelstellingen zijn niet bereikt. Gestructureerde werken wel en klantvraag op zich ook wel maar soms minder goed. Bij een project wilde de OG geen contact met stakeholders. Efficiency en effectiviteit kunnen veel beter. V&V moet meer tijdens proces en niet na oplevering.
3. Ja, bijv. bij A2-Hooggelegen is SE heel goed toegepast en met succes. Alles wordt aantoonbaar gemaakt (transparanter), faalkosten kunnen voorkomen worden met SE en uitvoerder wordt betrokken bij SE (volgens principes ervan). Bij systeemintegratie en faalkosten zit veel geld betrokken. Vooral bij grote projecten waar veel faalkosten kunnen zijn, is het toepassen van SE soms noodzakelijk.
Bij traditioneel had je veel aanpassingen bij DO. Met SE maak je met kleine schetsen al ontwerpen.
4. Toepassing van SE moet alleen over ontwerpproces gaan.

V&V gebeurt nu te laat.

Toevoegen van eisen moet op juiste plek en juiste tijd gebeuren.

Decompositie kan beter.

Stakeholders betrekken bij project moet meer en dit geldt ook voor MCA.

Men heeft soms moeite verschillen duidelijk te maken.

Wegingsfactoren bij trade-off zijn moeilijk te bepalen.

Pragmatischer omgaan is beter en je moet het gezamenlijk doen.

Ontwerpers vrijheid geven hoe ze gaan invulling geven.

Voor Trade-off hoef je niet alles in te vullen, alleen de belangrijkste zaken als het niet anders kan. Dat wil zeggen geen standaardisering want dan moet je alles per se invullen.

Dikke pakketten aan eisen belemmert soms.

Ontwerp wordt nu niet teruggekoppeld aan eisen en waarom en keuzes.

Niet te diep specificeren. Als er grote risico's zijn of politiek dan gaat men te diep specificeren.

Interview 3

1. Ja, SE is wel een expliciete manier maar het kan niet in een keer goed gaan. Vroeger gebeurden ook elementen van SE bij DHV en er werd steeds meer gespecificeerd en explicieter met SE.
Fokker ging failliet en die mensen gingen naar RWS en daar gelobbyd voor het toepassen van SE. Terwijl SE is niet bedacht voor civiele industrie maar voor vliegbouw en automotive. De projecten binnen civiel hebben steeds andere omgeving.
SE helpt met expliciet werken en soms wordt het doel voorbij geschoten. Maar in automotive prototype kan nog voor een paar jaar gaan.
Je moet ook weten wat je wel zet op papier en wat niet en niet iedereen leest V&V stukken.
2. SE zou faalkans kunnen voorkomen. Je kunt ook een transparant proces hebben en naar klant toe gaan met duidelijke keuzes en waarom die keuzes zijn gemaakt.
Sommige elementen van SE wordt hier toegepast zoals eisenanalyse, raakvlakken, V&V en als je dan tegen de ontwerpers verteld dat ze met SE bezig zijn, dan spannen ze wel zoals: "denk aan je interfaces mensen". EN ook met risico's werken en deze in acht nemen.
Ik vind dat de doestellingen nog niet bereikt zijn. Niet alles gebeurd zo expliciet als het moet en de waaroms over de keuze van een ontwerp zijn ook niet op papier maar meer in het hoofd gedaan.
Als je het verplicht stelt dan gaat dat wel en dan gaat het wel sneller na een tijdje.
SE levert wel op bij totale life-cycle maar bij alleen ontwerp, kost het juist meer tijd omdat je meerdere stappen zet en dit kost ook meer geld.

3. Ik geloof er wel in. Er worden minder fouten gemaakt en expliciet is beter. En bij veranderen van eisen zijn ze herleidbaar. In geheel proces zie ik wel potentie maar in ontwerpproces zijn sommige elementen wel goed terwijl anderen het duurder maken.
4. Ik zie geen directe tekortkoming in SE.

Standaardisering binnen woningbouw past wel goed. Bij Infra is het moeilijk alles in een catalogoog te stoppen en overal altijd prefab te doen.

Zuivere SE kan niet zo goed binnen civiel en SE moet ook op goede manier gebeuren. Bij sommige projecten moeten een aantal elementen van SE wel eb bij andere niet.

Risicoanalyse en interface/raakvlakmanagement moeten altijd gebeuren.

Stakeholders bespreken we in sessies met de klant maar nu kan het beter als je het expliciet maakt want dan kun je teruggrijpen en aantonen.

Ontwerp gebeurt bij ons wel top-down maar het kost dan meer tijd. Ik laat de ontwerpers nadenken over eisen maar niet dat ze een groot boek van eisen moeten maken en dus niet te diep specificeren. We zijn geen auto-industrie en moet soms anders.

Trade-off gebeurt nog impliciet en waarom een keuze wordt gemaakt is minder duidelijk.

Verificatiemethode zijn wed nog aan het ontwikkelen maar nu gebeurt het met een lijst met eisen.

Subjectieve en niet maartbare eisen, die worden maatbaar gemaakt en terug gegaan naar de klant om ze scherper te krijger. Validatie doen we met 3-D modellen en filmpjes aan de klant te laten zien en als er iets niet goed blijkt te zijn dan passen we het aan.

Raakvlakken worden door een team gedaan dat gaat goed. Raakvlakken worden beheerst door ze te benoemen en dan gesprek voeren met project/ontwerpleiders of andere desbetreffende persoon en dan een oplossing voor bedenken.

Interview 4

Systems Engineering helps us with scope which can change in the beginning. When the scope changes the requirements change too and this causes delays and mistakes if things are not structures. With SE and its tree's we can communicate and discuss with the client better and we can easier see which requirements (should) change when the scope is altered. This is possible with SE because things needs to be recorded and written down and the tree's give a good overview of the project.

There's has been very much attention for SE through courses and lectures. Especially when working with D&C contracts I saw it was good to know more about SE as well. The projects in which SE was used and I have been involved with, the team members had a lot of knowledge on SE and got these courses about how to use Relatics and SE templates for application in the projects.

1. Yes it is explicit, however, things depend on people's discipline and how the management requires and demands to work according to the theory.
I don't think any civil project can be done just in one shot especially the large and complex projects which go wrong sooner than smaller ones. Using SE obligates you to work explicitly. It happens that for example project members change or replaced. If everything goes the way SE describes (e.g. explicit and clear), new members don't have to search and won't forget the necessary information needed during the process. I must say, discipline is required and they should record what they do and why they take such a decision. In practice we see that people do not have discipline because it is not demanded or the management is not strict enough so people tend to choose not to work explicit every time.
2. Not enough and it should be better than this. Not all elements are implemented because the project leaders don't demand these so it's up to project members how far they want to go in using SE. If the management seriously requires the project members to go through all aspects of SE in every project, I'm sure positive changes will happen because fewer mistakes will be done and that contributes to better results and faster deliveries.
3. It's still in development and it's getting better but I certainly see potential in SE for the future. Things need to be done structures and complete. A risks database is going to be linked to SE templates. Along with BIM (Building Information Modelling) which is the future of building Industry SE will contribute a lot. We need to force discipline within our teams to use SE better and reach these goals and improve our results in practice as well. Also the use of SE should be made simpler and encouraged so that no one specifically asks other to use SE but it becomes a must and the easier way.
4. Verification steps need to get more attention when a product is being produced and the output needs to be checked if it meets all the requirements or not. I don't see that happening in practice really satisfying enough and this should be improved. Validation part is more for the client and he needs to approve the results.
Also we really need more focus on using and applying SE correctly and fully which does not happen right now.
5. A new approach or tool is not used just for the sake of doing something new but it goes with clients' wishes and demands. When the client asks for it or is in need of it, the market should provide. Another reason could be to enhance profit.

Things should be standardized to make the processes go easier in complex projects. Also the client should stop specifying too much and or too deep. Instead, the client should define the scope and initial requirements very sharp and clear. He should let the market decide. Also by encouraging the contractor through incentives or other form of support, the client can manage the project towards a good direction.

Interview 5

The market is in change and within the infrastructure projects these changes needs to be implemented. A broad use and implementation of SE is such a change and the question is how. Within the infrastructure unit of DHV, we deliver services in regard to using and improving SE both internally and externally. We contribute to distribute SE and improve the understanding of it. At our unit, we'd like to be the information and the knowledge center within the DHV in regard to SE. By applying the theory of SE in the projects and involve everyone in there, the understanding towards SE will grow. I must say this process is not going fast enough.

1. That SE is an explicit way speaks for itself.

The thing is that complexity in projects is increasing. There's need for standard agreements between parties but also within a team. Who's responsible for what? SE is a way to fix the agreements. A lot of characteristics of SE can be found in other methods and one cannot escape from it. So there's a need for a structured way in which a collection of agreements (requirements, risks, tasks) is explicit and everyone can see what and how to do things.

2. It differs per project. It seems a big step to reach full implementation of SE and at RWS the aim is to reach level 3 (out of 5) of maturity. Right now, we're somewhere within level 1 and 2 and it's going a bit slow and so I'm not happy with this speed.

When it comes in practice to some projects I can say in some projects like broadening of A2 and VIA15 the implementation of SE went very well and it seems SE works positives here.

While in the project Noord-Zuid-line it doesn't change the overall results and actually it's been hard there when using SE. This can be caused due to higher level of complexity in N-Z-line as well as the prevalent culture in that project and different parties. There were a lot of fragmentations with N-Z-line and a central coordination and control is very tough there. However, SE did contribute to explicit working in N-Z-line.

Basically, SE does not reduce complexity itself but SE makes complexity more manageable.

3. It's not only about added value but it's an inevitable fact that a system for agreements (Dutch: afsprakenstelsel) is necessary due to all kind of risks and demands in projects. A different approach other than SE would be possible too, but the elements of SE will be recognizable in that approach as well. So, the form of the model (V-model, waterfall model etc.) is not important but the elements in it (clarifying the demands and expectations, risks, verification & validation, decomposition of the problem etc.). Previously there were some models as well like the waterfall model and RVOI as standard forms and later after introducing the concept of Integrated Contracts (innovative contracts), RWS and ProRail decided to use SE as the suitable tool for this. It's not clear why SE but probably because it worked well in other industries. Previously things were solution-oriented while now they're functional oriented and I believe that

designing is choosing and this new approach with SE is suitable for this. It's necessary that everyone who's involved in the project can understand the 'problem' and can think from that perspective instead of jumping to the solutions immediately.

4. There are certain topics we are still dealing with. As mentioned before the implementation from theory to practice and the gap between these two. There's a lack of people who are both familiar with technical aspects and the design processes. Engineers/managers who are a bridge and can both think broad and deep are needed in complex projects.

ISO15288 is not understood well by many and the level of thinking broad when using SE is not sufficient.

SE and the form of contract should be seen separately. The question should be, what does the client want and based on the need a form of a contract is chosen and SE is just a tool to help you in the project. It depends on RWS or the client how far things should be specified.

Interview 6

1. Het is wel expliciet als het toegepast wordt volgens de theorie maar dat gebeurt niet altijd in de praktijk. Bijvoorbeeld, het expliciet maken van keuzes gebeurt nog niet en herleidbaar maken van keuzes ook te weinig. Als je SE toepast dan moet je veel iteratief doen. Eisen worden wel expliciet maar hoe ze tot stand gekomen zijn niet. Expliciet maken betekent ook: wat gaan we hieraan doen en hoe?
Soms worden we later betrokken bij een project en in die fase is dus niet duidelijk waar de eisen vandaan komen.
Het moet duidelijk zijn als iemand vraagt: wat bedoel je met die eis?
Bij strijdige eisen ga je terug naar de klant met wel voorstellen hoe het anders zou kunnen.
Soms zijn de raakvlakken niet bekend en men denkt dat: "het komt wel goed".
Vastleggen van raakvlakken gebeurt nu weinig.
In een keer goed kan niet want het blijft mensenwerk maar kans op fouten wordt wel kleiner met SE. Want je ziet ook waar een fout vandaan komt omdat het traceerbaar is met SE. Vooral bij wijzigen van eisen komen fouten voor.
2. Binnen Nederland is lang niet alle doeleinden bereikt. In de bouwwereld zijn sommige elementen van SE wel goed toegepast en daar zijn de doelen wel bereikt.
3. Ja, op den duur kan iets opleveren maar het kost tijd.
Dat is omdat met ervaring en gestructureerd werken minder fouten worden gemaakt en er wordt stapsgewijs gewerkt en je kunt sneller bijsturen als het fout gaat.
Het is nog steeds bottom-up maar we beginnen langzaam richting top-down.
Dat komt door dat veel besluiten vanuit overheden komen en ze willen heel uitgebreide ontwerpen terwijl ze ook meer ruimte willen maken voor de markt.

Bij ontwerpen wordt expert judgement gedaan en weinig trade-offs. Soms is de probleemstelling en doel niet duidelijk en daardoor de eisen ook niet.

SE moet gewoon vanaf het begin van project worden toegepast.

Samenwerking hangt af per groep, als je mensen niet kent dan is het moeilijk, bij NACO gaat heel goed bijvoorbeeld.

4. We zijn nu nog bezig alles over SE in documenten te zetten en weinig Integraal database/Informatie management. Iedereen kent de theorie van SE wel maar weinig aandacht voor de implementatie ervan. Er moet meer gestuurd worden als SE wordt toegepast.

Validatie gebeurt met de klant en niet met ons want hij moet het goedkeuren en dan is het gevalideerd. Als de verificatie heel goed gaat en goede probleemstelling en doelstelling is gedefinieerd en deze worden nagekeken in het ontwerp dan is de kans heel klein dat bij validatie iets fout gaat.

SE levert vooral op bij projecten waarbij veel beheer en onderhoud nodig is en langer voortduurt.

Interview 7

1. Ja, het is een expliciete manier. Werkt niet in een keer goed maar het wordt steeds beter.
2. De doelstellingen zijn ten dele wel bereikt Tijdens werk wordt het niet goed toegepast omdat het een extra handeling is. SE heeft wel toegevoegde waarde en uit ervaring zeg ik dat het ook aan efficiëntie en effectiviteit werkt. Wensen en eisen van de klant worden vertroebeld tijdens proces maar met SE leg je ze vast en kun je terugkijken.
3. Ja, met name in eisenspecificatie. Ontwerpkeuzes kunnen beter worden gemaakt en uitgelegd maar ook bij veranderen van eisen kun je met SE beter bijhouden. Je kan ook makkelijker aan de klant vertellen hoe je tot een keuze bent gekomen.
4. Het moet zo makkelijk mogelijk zijn en niet als een belemmering worden gezien. Men moet het nut ervan kunnen zien. Er moeten meer succesprojecten met SE worden laten zien en meer praktische voorbeelden. Maar toch vind ik dat SE niks nieuws is; het is expliciet maken en zorgvuldiger controleren. Je moet zorgen dat mensen het gaan gebruiken.

Interview 8

DHV was involved in the early stages of High Speed Line (HSL) about 12 years ago and there we came across elements of SE while it was not known to anyone yet. Functional specification was something we were facing there and we had learned a lot. Things had to be done in a structured way and as an Integral Design methodology, both during the planning and feasibility procedure as well as for the contractor. The process should have been explicit and referable to requirement so we could see why a choice has been done.

Later the government started to get interest in Functional Specifying of a problem. DHV has

experience and the basic knowledge on that and therefore we could play a good role in the development of SE. We could use our expertise to give workshops and trainings to other companies which were not so far. After that ISO15288 was used as a main reference for development of SE.

The V-model is basically Systems Architecture of a project and its bottom is the SE and the right side is System Integration.

1. Yes, SE is absolutely an explicit way of working. Through SE you are forced to think functional-oriented when solving problems.
Having a good project in one shot does not depend much on using SE or not. The teamwork and the dynamic around a project do not allow a unique project to be good at once. SE is useful to manage things better and have control over certain aspects like quality.
2. I believe it contributes to managing projects better and easier. Before the implementation of SE things could go well too, however, the project are getting larger and more complex and new ways of solving problems are necessary and since SE makes the project getting structures, it reduces the change of making big mistakes.
3. Yes as previous said I see and hear that SE works the more is understood well. If it matures then it functions well and efficient and effective results are to be expected.
4. I am not sure about a specific part but I can imagine it's much better if the V&V phase is more clear and standardized and the implementation of SE overall is understood in practice as well. The requirements don't have to go very deep because then the overview will be lost
5. When the previous/current method does not work well or inefficient then new tools/ways are needed. Also if the demands and expectations change from a project team in general.

What I like to add is that getting a (complex) construction project well in one shot, is actually not possible just with SE, it does only help you to progress and have better results at the end and less surprises.

Interview 9

DHV has paid a lot of attention for implementing SE by organizing courses and workshops. Although, people tend to fall back to the previous approach (without SE) because the step from theory to practice seems not that easy.

1. I believe we can say it's an explicit way in regard to recording and documentation of the requirements and demands. However, solution cannot be explicit just because of SE because different solutions may fit in the solution space and meet the all the requirements.
I do not believe that a project can be good at once just because of SE. It does help to structure projects and creating better insight and overview during the projects. So

there's no guarantee for success in one time.

2. For the most part the goals have been achieved and the better SE is better understood, the more it delivers. If people know how to implement it then I think definitely SE works effective and more efficient. Especially in large and complex projects because there you need to organize a lot of information and SE is a good tool that can be used to get things organized and structured.

Although, I have no scientific proof for that except from what I hear from people around me and what they are experiencing with SE.

3. I do see potential in SE as a tool in the projects. Working in a structures way yields more benefit en SE is such an approach/tool to achieve that.

If RWS and other clients wouldn't have asked/required the market to use SE, then perhaps other tools/approaches would have been considered.

I believe that the best contract form in projects is the alliance model. The parties work together to achieve the same goal and if they share the risks and the profits they'll do their best to work more efficient and therefore they will not reckon off each other.

But because the government wants things as cheap and good as possible while shifting the risks towards the market, it does not choose for alliance as often.

4. The question remains how far and to which extent will you go when the requirements are going to be specified? So the depth of the v-model should be standardized to know when in a [project is needed to go how far. The more influence a client wants to have , the more he needs to specify and go deeper before handing over to the contractor.
5. A new approach benefits if it adds value to the project in terms of money, sustainability, time and aesthetics for the client. And when one is looking for more efficiency, new tools get interesting.

Interview 10 Railbouw

1. Ja, het is wel expliciet. Je neemt makkelijker een stap terug als je verdwaald bent en zie je waar je staat. En het gaan niet in een keer goed.

2. Nee, nog niet bereikt. Theoretisch wel maar in praktijk nog niet. Bij Rail wordt ook bij kleine projecten SE toegepast en er is niet te veel ervaring.

Meestal gebeurt alles nog bottom-up en top-down is moeilijk en binnen Railbouw is het afhankelijk van omgeving en de mogelijkheden worden eerst bekeken en dan pas eisen opgesteld.

Er is nu nog te weinig communicatie met de klant en stakeholders. En nu wordt er eerst ontworpen en dan pas naar de klant. Hoewel trade-offs worden wel gemaakt.

Ook wordt er eerst wat ontworpen en dan pas de eisen gemaakt.

Stakeholderanalyse wordt ook gemaakt. Er wordt risicogestuurd ontworpen maar risicomatrix wordt te weinig gebruikt. Voor validatie gaan we naar de klant.

Voor raakvlakken maken we een overzicht van alles en eisen worden gekoppeld aan

raakvlakken. We niet veel subsystemen en vooral externe.

3. Ja, kan wel iets halen door expliciet te werken omdat je meer efficiency krijgt. NU wordt er nog vanuit ervaring ontworpen. Met SE kun je terug naar de klant en leg je de keuzes beter uit.
4. Er is nu weinig ervaring met SE praktische gezien maar het heeft wel toegevoegde waarde. Eisen worden wel SMART gemaakt en subjectieve en moeilijke eisen worden in onderliggende eisen duidelijker. Zoals een topeis als veiligheid -->meer lichten en niet veel bochten enz.

We gebruiken nu sommige elementen uit SE. Bij complexe en grote projecten is SE beter te gebruiken maar bij ons is het minder complex.

Meer overgaan naar standaardiseren is wel een goed idee, met of zonder SE. Hoewel de omgeving heeft veel invloed bij Infra en dat kan niet altijd via standaardmanieren.

Interview regarding the Design phase

Interview 11

Questions 1,2,3. N211A, D&C, for Provincie Zuid-Holland, large maintenance. In this project simple SE has been used when making requirements' trees. No special software was used like Relatics.

Actually, SE would have been used for the entire design process but it did not happen and in some steps SE was used and some elements were left out.

Another project was replacing 8 bridges for Gemeente Westland in a D7C contract and the third project was 4 fixed bridges for Noord Holland in an E&C contract. For these two projects I was the project leader.

The fourth project is the A2 Bypass/Ring road in Den Bosch for RWS. In here I worked a design leader. All of these project are finished by now and in all of them SE was used.

Zuid-West ring road Gouda is another one, in some phases SE was used and this project is finished in the summer.

4. I believe yes, there's been enough attention paid to SE and the key figures in the company and projects do have sufficient knowledge about SE. I must say that not everyone in the company know SE well and the process goes slow because people tend to work the way they are used to.

5. List of requirements was made for all the projects.

6. List of wishes and boundary conditions (Dutch: randvoorwaarden) was not made except for Zuid-West ring road Gouda. Usually there's no separate list for wishes and boundary conditions and these things are available in the Nota's/Memo's.

7. Yes, the structure is linked to the object trees. Per object there should be Functional requirements, Interface requirements and Aspect requirements. But no such trees were made for wishes and boundary conditions.

8. Yes it is needed because then you can see what's missing and how complete your structures

are. This was you can formulate your tree's easier along with its decompositions. Also this is a handy way to look up something in the trees very quick.

9. The problem definition is more implicit and it's recorded in the tender document/request for quote (Dutch: offerteaanvraag), but not really explicit.

10. As much as possible yes. It's a continuous learning process. Sometimes some requirements were formulated but the contractor told us they do not consider those as requirements but more as boundary conditions, wishes or baseline/starting points (Dutch: uitgangspunten).

11. Yes it happened. However, sometimes it seems that the checking was incomplete afterwards. It also happened that some requirements are not formulated well which are in contradiction to the handbooks.

12. It depends in which phase of a project you are. Once it happened that some requirements were not correct formulated and the contractor had problems with these and a claim for damages was issued.

13. It should be but in practice it is not enough and some information is unclear or not complete. I can say that having everything alright in one shot is not so possible. Especially during the design process some information is missing and this causes problems and delays. For instance in the project N211A new information came in and this causes mistakes because things cannot be adjusted quickly. Although, this has not so much to do with SE, one could think of these risks in the earlier stages with SE and be prepared for the new information/date given later.

Changes and alternations happen often in projects. This alteration and modifications delay the process but also mistakes and errors in other phases.

14. Through stakeholders, references, experts and sometimes external sources but also the designers use their own experiences.

15. When you want to take a step or make a decision etc. you write it down or record it and then you discuss the issues with other actors through emails, iRoom, calling up, meetings, reports etc.

16. The client is being informed when choices are made and if he agrees things go on as usual.

17. Not really, the more we get closer to realization phase the more specific information we need.

18. Not always but usually there's such a relation. I must say that a stakeholder analysis does not happen and this is a part of SE.

19. Yes, always.

20. Relatics and Excel. Relatics is very handy and it's used also as a database. In smaller projects Excel is easy to use with the formats we have.

21. Tree structures (functional), requirements specifications, design documents (calculations, drawings), Memo's.

22. Risk analyses have been carried out for the project but it was not always a part of the design process and sometimes not so explicit. They have not been used often because it's in designers' minds and thus used abstract when designing.

23. Usually there's more information needed which might matter.

24. Yes but not in design choices?
25. As a baseline for the design; usually as we used to do it before implementing SE. It happens by instincts and things don't work out well in just one time. A verification matrix should be present. Once it went wrong although such a matrix existed, probably not used well. The designing should be keener and they need to understand the requirements well and it happens that they do not read all these lists of requirements. Sometime even we have designs and then thinking more about requirements which are missing.
26. Usually it does but every time it's different. There need to be discussions and sharing of information together. Sometimes people have different images in their mind for one problem. For example it is said that a berm should be 2 meter but it's not clear if it is meant to be 2 meter everywhere or it may be 1,80 m in some section as well?
27. The client is involved but less explicit through meetings, calling ups.
28. Sometimes there are design choices made and they are recorded in Memo's. Designers make a choice but it's more in their own mind why they chose for that so it's not explicit. I do miss the assessments and trade-off which don't happen every time.
29. It's different every time; the design products, tree structures, requirement specifications and then risk matrix, in some cases V&V methods.
30. That's also different in each project. I once experienced that Verification matrix was not required but it was made available and in some cases a (deeper) risk analysis.
31. Not really, just the draft notes for the designs (Dutch; opzet van ontwerpnota).
32. Yes, it is enough but sometime little things can be missing.
33. Evaluation does not happen enough. Maybe the quality manager should be involved in this and everyone needs to learn from previous mistakes. [to avoid making the same mistakes again!]
34. There are standard forms but evaluation happens more in a conversation rather than on paper with forms. Usually things are not written down.
35. Through open conversations and discussions and sometimes instinctively.
36. No, not in the evaluation.
37. It's not done but it should.
38. Sometime there are midterm evaluations too but usually things happen afterwards.
39. There are oral consultation and discussions but not explicit.
40. no standard technics
41. No
42. Yes it must.
43. It's not that transparent. Sometimes orally but not explicitly.
44. Usually it doesn't happen. When it does happen it would be orally and this is full of risks and it's not explicit too.
45. The client is involved and he's asked to sign if the product is according to requirement specifications
46. If there is a Verification matrix made then yes, for each requirement there will be a verification and validation method (inspection, vision etc.)

47. It happens but usually once in the beginning and once at the end.
48. Usually top-down while requirements' list is sometime bottom-up.
49. Yes it works.
50. Yes, it wasn't thought well about in previous stages and the consideration might have been weak. Things are done to do it quicker and to save money and the consequences are frustrations in latter phases but with better quality.
51. Yes, very often.
52. Yes, it works well to determine the scope.
53. It's tough to get the decomposition right in just one try. It needs adjustments.
54. It's complicated. Usually implicitly and intuitively based on previous experiences of the project leaders. We do miss a tool in that area. Everyone has a different level and different responsibilities and people have their own opinions in such issues. Maybe introducing a list of interfaces in SE.
55. The cooperation is ok. With iRooms being in used things go faster and easier, especially when Risk and interface issues come up.
56. It's different everytime and depends on the scape of the project too as well as the level of details. Generally speaking the whole core is kept at the center.
57. Yes it's possible but it needs effort and expertise.
58. Yes it's explicit if things go according to theory but in practice things are not always done explicitly. Project can't be good at once.
59. The goals are still not proven to have been achieved because the process needs time. It's going pretty slow.
60. Yes, due to lack of good skills (in practical way) it's not understood well and not appreciated.
61. Interface management, fixed trade-offs methods, verification-matrix, involvement of client in different phases lacks.

Interview 12

- 1,2,3. Project VIA15 bij Arnhem, DBFM en ik heb daar als adviseur SE gewerkt. We zijn nu halverwege contract en planfase.
4. Absoluut, cursussen, learning on the job.
5. Ja, we hebben startnotities, planstudies, probleemstelling, doelstelling.
6. Geen wensen apart.
7. Ja bomenstructuur.
8. Ja, omdat het beter structureert.
9. Ja, die heb ik zelf opgesteld en afgestemd met OG.
10. Niet altijd, vooral bij hoog abstractieniveau minder SMART
11. Absoluut, eisen worden met minimaal tweemensen gecontroleerd.
12. We stellen die eisen zelf op en voeren gesprekken. We kijken wat we beogen met elke eis en uit discussie en kunde maken we die eisen of passen we aan.
13. We stellen ze zelf op en overleggen als iets mist.
14. Overleg met de klant.
15. Eerst analyseren we alle stakeholders. Zowel interne als externe stakeholders zijn er. In

- gesprek met OG en ook door afspreken via email, telefoon worden ze bij betrokken.
16. OG betrekken is een integraal onderdeel. Als OG zelf al afspraken met andere stakeholders heeft gemaakt, is dat makkelijker voor ons.
 17. Niet echt.
 18. Jawel.
 19. Ja, dat gebeurt.
 20. Document-managementsysteem, SharePoint, ondersteunend Excel.
 21. Werkplan, verslagen van overleg.
 22. Ja, maar de details van risico's worden niet opgeschreven. Risicoanalyse wordt als tool gebruikt en men moet een balans vinden wanneer en hoe je hem gebruikt.
 23. Ja is voldoende.
 24. Geen aparte per fase.
 25. Als input voor het ontwerpen.
 26. Ik denk het wel, maar mensen interpreteren het anders daarom wordt er over gesproken in een overleg.
 27. Voorstel wordt gedaan aan OG en gesprekken gevoerd.
 28. Ja, en deze keuzes worden in ontwerpdocumenten vastgelegd.
 29. Ontwerp met verantwoording, verificatielijst.
 30. Weet ik niet.
 31. Ja, verschillende versies van documenten en verslagen.
 - 32 (Evaluatievragen). Geen inzicht.
 33. Ja de prestatie moet tegen alle eisen worden getest.
 34. Onderbouwing van het ontwerp, eisen bekijken en dan ontwerpen en weer terug kijken.
 35. Niet alle eisen zijn SMART en sommige zijn moeilijk meetbaar. Zulke eisen worden dan doorontwikkeld in sub-eisen om ze makkelijker te maken en met de OG besproken. Ook wordt er gekeken naar ontwerprichtlijnen.
 36. Door gesprekken te voeren met de OG en vragen of de oplossing voldoet met de tekeningen en i-Room.
 37. Bij voorkeur niet, alleen wordt voor elke eis V&V methoden gemaakt als dit per se gevraagd wordt. Omdat je hiermee de oplossingsruimte beperkt als je V&V methoden maakt.
 38. Ja.
 39. Top-down ontwerpen.
 40. Ja, dat kan, soms heb je wel schetsen nodig om een eis duidelijk te maken.
 41. Ja natuurlijk, OG wil iets wijzigen en dat veroorzaakt soms vertraging.
 42. Informeel wel.
 43. Ja, we maken decomposities.
 44. Ja, je moet handig knippen.
 45. Door raakvlakmatrix en deze wordt met overleg besproken en afspraken gemaakt. Vaak gebeurt het wel goed. Er moeten aparte documenten door aparte (raakvlak)manager worden gemaakt.
 46. Discipline gestuurd, hoofd van elke discipline vergadert met de ander.

47. Het geheel is centraal en dat is startpunt van overleg.
48. Ja zeker mogelijk.
49. Ja, het is zeker expliciet werken. In een keer goed gaan lukt niet. Elke project heeft zijn eigen dynamiek en omgeving en dus anders.
50. Omdat je expliciet werkt, helpt SE om beter te werken en als team wordt je gedwongen meer samen te werken. SE is een goede tool om efficiënter te zijn maar je moet het wel goed toepassen. Dit zeg ik uit ervaring. Nog niet alle doelstellingen zijn volledig bereikt maar wel op weg.
51. Ja, OG's worden steeds ondeskundiger. Met SE kun je laten zien dat je voldoet aan de eisen en waarom je een keuze hebt gemaakt.
52. Voor ontwerpers is moeilijk te zien wat SE is en ze beleven het als een extra handeling. Er is soms ook een gevoel dat je niks terug ziet.
Er moet dus meer goede voorbeelden worden laten zien waar SE juist en succesvol is toegepast. Ook dat je zonder SE makkelijker de fouten over het hoofd zou zien en risico's worden eerder ontdekt. Je moet ook flexibel kunnen omgaan met SE.

Interview 13

- 1, 2, 3. First project was Infra2 Den Bosch (D&C) and here I was design leader and I was not familiar with SE. The second project I was involved with as a design leader was A2 Hooggelegen near Utrecht (alliance contract) and here things went very well. Both projects are finished now.
4. There were many courses and lectures/workshops to understand SE.
5. Yes, the client demands and wants solutions and he sometime specifies more. In practice SE is more used to specify the demands.
6. Yes for both.
7. Yes there is. In the beginning there's a big amount of information and we have to find the ones we need.
8. Not that much. We have to make these trees we need by ourselves while there's a lot of various information available and we have to catch the good ones.
9. Yes, it's usually clear.
10. We can say it is. It happens that sometime it needs more clarification so it's then less clear.
11. Not really. There's discussion about how SMART really works and what it wants from us. Sometimes it's abstract and less clear what is meant by SMART and the question remains: is it correct the way how did it or is it not?
12. Yes, it was done.
13. We go to the client although it goes slow. And when it's a D&C contract the client expect you to solve it on your own and has not always an answer for you unless you come with solutions.
14. Not so clear. We go by intuition while having lots of information in front of us and we have to figure out what we need to reach the solution.
15. From the client at the first place in the contract. The rest through meetings or calling ups. I must say in alliance contract things went smoother.
16. Meetings and making reports and in the alliance more with iRooms.

17. Usually through meetings but it should go better because it's sometime rough the way it is. iRoom sessions are easier but also the client himself has to be find with how it should go.
18. No, the involvement of the client varies; in the beginning phases the client is more present but later he's less involved.
19. In principe wel
20. Ja, dat gebeurt wel, vooral met Relatics.
21. Bij A2 Hooggelegen vooral Relatics
Infra 2 vooral met Acces database
22. Startnotities, ontwerpnota tijdens het project en als laatstate verificatiematrix
23. Ja, een dergelijk Risico-analyse wordt uitgevoerd maar wat je daarna ermee doet is niet duidelijk.
24. Het is wel voldoende ja
25. In principe wel.
26. Niet altijd even goed, meer met gevoel. Trade-off zou beter zijn.
27. Er blijft niet veel ruimte over vanwege al die eisen en richtlijnen-> weinig keuze ruimte
28. Te weinig maar normaal via overleg en ook via e-mail en opbellen als er iets is.
29. Ja, trade-off bij varianten en deze worden vastgelegd in ontwerpnota's.
30. Dat verschilt, berekeningen, tekeningen en trade-off. Bij tweede project geen trade-off gemaakt.
31. Wat niet gevraagd wordt, wordt ook niet gemaakt.
32. Trade-off matrix met tekeningen, alleen bij aannemer gaat het anders, die kiest voor goedkoopste variant altijd.
33. Jawel, er wordt niet echt iets gemist.
- 34 (MCA). De criteria wordt wel meegenomen maar niet alles wordt uitgezocht. De beste die scoort (of op papier of in het hoofd) die wordt gekozen en dit wordt aan belangrijke figuur in project laten zien en overlegd. De afwegingen zijn niet altijd in evenwicht en de klant wordt niet bij betrokken. Alleen de gemaakte keuze wordt aan de klant laten zien.
- 35 (Trade-offs). Niet bekend. Bij A2 Hooggelegen werd er met kwaliteitssysteem van andere gedaan. Evalueren gebeurt wel maar verbeteringsprocessen niet.
36. Ja, dat moet.
37. Op ontwerpleidersniveau is dat een probleem. Ontwerper zelf wil ontwerpen maar moet ook verificatiematrix bijhouden. In verificatie nota's worden de afwijkingen geschreven.
38. Dit is een probleempunt. Tekstueel worden pogingen gedaan maar ze werkelijk aangetoond worden is nog de vraag.
39. Bij A2-Hooggelegen gebeurde met iRoom, OG en andere belangrijke Stakeholder laten zien hoe het wordt als afronding van het ontwerp.
Er is verder te weinig naar alle eisen gekeken en niet iedereen is even op de hoogte van eisen. Vooral als Utrecht nieuwe mensen stuurde die niet wisten waar we staan. Bij DHV gebeurt verificatie en validatie wel maar bij aannemers niet.
40. Nee, voor ontwerpproces wordt er gezegd: zie tekeningen. Er moet meer gedaan worden aan dit.

41. Ja
42. Een mengelmoes van beide.
43. Wel mogelijk maar er is veel erfenis bij veel mensen van traditionele methode. Keuzes worden soms op ervaring gemaakt en niet zo zeer op elke criteria afgewogen.
44. Ja vaak, en het is voor proces wel storend. Veroorzaakt door een scopewijziging vanuit de klant. En dan om raakvlakken integraal afstemmen is een probleem, dus er moet meer integraal eigenlijk.
45. Ja soms. Raakvlakken moeten dus meer integraal en daarom meer cycli nodig.
46. Ja, en het is goed bij SE maar niet bij ontwerpen want ontwerpen moet als geheel worden gezien en niet opsplitsen in stukken. Decompositie moet bij eisen en probleem maar niet bij het ontwerp want dan ontstaan veel meer raakvlakken en onbeheersbaar.
47. Ja maar niet in ontwerp. Dit zou minder inzicht veroorzaken.
48. Heel slecht in beide projecten. Zelfs met dat raakvlak manager niet goed genoeg. Er is heel veel inhoudelijke kennis noodzakelijk omdat er te veel raakvlakken zijn.
49. Veel in cyclussen en niet integraal. Nog steeds in eilandjes en dus gewoon op oude manier. Er moet beter gestuurd worden om beter en integraal samen te werken.
50. Door veel te knippen wordt het geheel kwijt geraakt maar op zich heeft dit niet zo veel met SE te maken. Zonder SE gebeurt dit ook.
51. Ja het is wel mogelijk maar mensen moeten durven en over drempel heen en dit moet ook gestimuleerd worden want nu loopt het moeizaam.
52. Ja het is wel expliciet mits goed gebruikt maar het wordt slecht toegepast. Vooral ON past SE niet goed toe.
53. Bij OG wel maar bij ON niet. SE is een goede manier als het goed toegepast wordt.
54. Ja duidelijk.
55. Men moet een balans kunnen vinden. Soms wordt te veel gewerkt (doorgeslagen) en er moeten niet veel bomen komen. Mensen moeten het vooral begrijpen en juist gebruiken. Nieuwe werkwijze moet laten zien worden dat het werkt. Nu wordt SE ingewikkeld gepresenteerd en men denkt; het zit me meer in de weg. Het moet dus simpeler worden laten zien zodat mensen zelf SE gaan toepassen.

Interview 14 Real State & Gebouwen

- 1,2,3. European patent office project, nieuwe gebouw, D&B, aanbestedingsfase. SE is nieuw binnen Real State (2 jaar).
4. Kennis in projecten geleerd.
5. Ja met Relatics worden uitgangspunten, wensen en eisen gedaan. Maar ook systemen, elementen en componenten worden bepaald. Bij gebouwen ook functionele eisen, bomen enz. worden gemaakt. Gebouw is 1 object en dan kamers, ruimte, vergaderzalen enz. subsystemen en ook andere disciplines zoals installaties e.d.
6. Het ging achterwaarts, bottom-up gedaan en niet gelijk in bomen.
7. In workshops wordt gekeken met de OG wat hij wil en aangevuld door expertise van onze kant en dan is het duidelijk wat en hoe voor ons terwijl voor de klant nog onduidelijk is.

8. SMART beogen we wel, volgens normen.
9. Ja
10. Ligt aan de eis, wensen invullen met eisen en teruggekoppeld aan OG.
11. Intensieve relatie met OG
12. Minder gecommuniceerd, er zijn minder actoren dan bij Infra. En er is ook een omgevingsmanager. Buren worden geïnformeerd en OG beslist.
13. Veelal in de vergunning vastgelegd.
14. Eisen aan functies en objecten vragen we aan OG
15. Model voor PvE.
16. Minder dan bij infra maar wel tussentijdse rapporten
17. Risico worden op procesniveau gedaan en zo'n risicoanalyse wordt bij besluitvorming gebruikt en bijgehouden
18. Hier niet, er worden niet veel varianten gemaakt maar vooral beste keuzes gemaakt
19. Eisen as input voor ON en vanuit die eisen wordt er ontworpen maar soms is het lastig ontwerpen met eisen. Architecten vinden het moeilijk SMART te ontwerpen en moet vaak met veel foto's.
20. Ja bij elke fase wordt keuzes gemaakt.
21. Materiaalstaat, kleuren, berekening, tekening, uitvoeringsmethode
22. Geen trade-off gemaakt maar rechttoe rechtaan gebaseerd op ervaring en ontwerpnota's maar per product wordt er wel trade-off gemaakt.
23. Architecten met foto's en de rest is meestal op ervaring
24. Verificatierapporten wordt opgesteld door iemand anders en gecontroleerd
25. Met tekeningen en berekeningen
26. Nog niet bekend, best practise en naar OG gaan en dan besluitvorming wordt per fase gedaan
27. Nee
28. Bottom-up maar ook top-down is mogelijk
29. Aannemer maakt WBS en decomposities
30. Raakvlakken worden op ervaring beheerst en je hebt interne en weinig externe raakvlakken
31. Onderlinge vergadering, bellen, tekeningen van elkaar bekijken, met SE wordt het gestructureerder maar niet makkelijker
32. Subsystemen en iedere met aparte expertise
33. SE is wel expliciet maar niet in 1 keer goed. Functioneel specificeren is moeilijk soms
34. Nee, we zijn net begonnen met SE binnen gebouwen en maken gebruik van de ervaring bij Infra
35. Potentie is er wel en ik ben voorstander van gestructureerd werken en overdraagbaarheid wordt beter. Maar soms maakt SE het ons ook te zwaar. Dit project kon in principe ook zonder SE gebeuren alleen met SE en Relatics heb je meer grip op project.
36. We moeten leren om SE goed en effectief te gebruiken maar we zijn er nog niet zover en we zijn bezig met kennisoverdrachten uit de Infra.

Interview 15, Waterbouw

- 1,2,3. RWS vraagt SE ook bij rivier en waterbouw
Project ontpoldering Noordwaard , RWS, D&C, zit in uitvoering en ik was SE'er.
4. Cursussen, hoe meer toepassing hoe beter.
5. Geen lijst met eisen in de planfase maar meer aanvullen omdat veel dingen zijn al vast bij polderprojecten en ook omdat RWS veel nauwkeurige ramingen heeft gemaakt en dan pas komen de andere eisen.
6. Hier zat alles al verwerkt maar bij andere projecten gaat het beter bij klantenvragen en wensen halen we bij SH door gesprekken te voeren en eisen uit documenten.
7. Ja dat is vaak bekend.
8. Ja in principe wel SMART.
9. Ja dat doe je ook zelf en elkaar controleren.
10. Doorsturen naar de klant en deze te bespreken. Kiezen bij strijdige eisen en SH moet keuzes maken. Onvolledige eisen volledig maken, zelf of OG. Kritische eisen meer specificeren.
11. Extra onderzoek doen en vragen bij de klant.
12. Terugkoppelen naar OG
13. Bij hen zitten om een tafel en gesprekken voeren maar ook niet te veel.
14. Klant wordt constant op de hoogte gehouden en Relatics wordt aan hem laten zien en besproken
15. Bij ons heb je niet zo veel VO, DO, UO. OG zegt dat de aannemer moet berekenen.
16. Ja, eisen worden aan contracteisen gekoppeld en we weten wie deze eisen hebben gesteld via Relatics
17. Ja bij Relatics word je gedwongen dat te doen.
18. Soms database, lijsten maar vooral Relatics.
19. Vraagspecificaties met verschillende versies.
20. Risico's worden als basis in tijd en geld uitgedrukt en risicogestuurd specificeren.
21. Ja, maar we genereren geen echte varianten en als het niet voldoende is dan praten we met OG. Ontwerp en indeling liggen al vast. Vaak bij waterbouw zijn veel dingen al bekend.
22. Voor details van kleine ontwerpen wel varianten maar niet voor heel systeem.
23. Klant wil vraagspecificatie zien, met versies.
24. Evaluatie en trade-off: Er wordt beargumenteerd met vakkennis en met ervaring kom je op iets uit. Alles moet voldoen aan regels en wetten en tevens wordt met OG en SH's gepraat.
- 25 (69). Ja, met berekeningen, hoogtemetingen.
26. Eisen SMART maken met de klant
27. OG krijgt vraagspecificatie en hij controleert/toetst of het is gemaakt naar zijn wensen of verkeerd geïnterpreteerd. OG kan technische modellen niet beoordelen en ze vertrouwen erop maar soms wordt een ander ingenieursbureau ingeschakeld om het te toetsen.
28. Verificatiemethode wel maar validatiemethode minder
29. Bij voorkeur top-down maar in praktijk ook bottom-up
30. Ja het is wel mogelijk. Soms wel vaag als de OG wil weten hoeveel iets kost want dan moet je meer details hebben

31. Soms maar niet vaak.
32. Niet echt
33. Ja, functie/objectenboom worden gemaakt en hoofdvraag wordt in stukken gedeeld.
34. Raakvlakanalyse gemaakt en er worden eisen opgesteld voor raakvlakken
35. Teamoverleg, technische manager adviseert, contractmanager en omgevingsmanager helpen hiermee, maar onderling en bij OG met email, overleg, bellen enz.
36. Vaak het subsysteem
37. Bij grote projecten niet zo maar wel mogelijk. Bij kleine projecten is het makkelijker mogelijk. Bij grote projecten heb je een persoon nodig om het geheel bij elkaar te houden.
38. Het is wel expliciet maar in praktijk is het minder en het levert wel op als je expliciet doet. Het kan nooit in een keer goed maar grote lijnen moeten wel vast zijn vanaf het begin.
39. Gestructureerd wel. Voor grote projecten wel effectief en efficiënt maar voor kleine projecten niet. Maar het is moeilijk te meten want ook zonder SE is het mogelijk.
40. Wel handig met top-down en SE is handige methode op zich vooral voor grote projecten.
41. Bij waterbouw ga je al vanaf het begin te diep vanwege andere redenen. In praktijk gaat het anders dan in de theorie.

Interview 16

- 1.2.3, Regiotram Groningen, DBFMO in aanbestedingsfase. Ik heb bij het schrijven van specificaties gewerkt.
4. Ja.
5. Ja, wel beter als je dat apart doet.
6. Ja, eisenboom, objectenboom, functionele analyses.
7. Structuur vind ik noodzakelijk
8. Ja.
9. Uiteindelijk wel SMART, op systeemniveau is het moeilijk maar op detailniveau makkelijker.
10. Ja, wordt wel gedaan.
11. Strijdige eisen kwamen veel voor en deze werden besproken en dan naar projectleider gestuurd en hij weer naar de klant als het nodig was en het was niet makkelijk.
12. Jawel maar veel uit het hoofd.
13. Door contact me de klant en andere disciplines.
14. Via omgevingsmanager
15. Klant uitgenodigd voor overleg
16. Wordt gelegenheid gegeven om eisen in te brengen. Er was wel verschil bij VO fase in dit project en toen werden wij ingeschakeld om met SE te doen.
17. Regiotram gaf niet aan (uit de vorige fase) wie wat voor eis had.
18. Ja
19. Relatics.
20. Vraagspecificaties, ontwerptekeningen, maar we waren later ingeschakeld
21. Risicomatrix ja maar het is niet sturend geweest bij eisen specificeren.
22. Ja

23. Jawel, VO en DO en publieke opinie wordt er ook bijgehaald.
 24. Deels was het al gebeurd en soms werd het ontwerp aangepast. Niet in goede volgorde.
 25. Die moet wel komen.
 26. Veel betrokken, deel met trade-off en ook publiek gemaakt.
 27. Kaderdocumenten, vraagspecificaties, referentieontwerp.
 - 28 (69). Ja dat moet wel
 29. Bespreken en overleggen met verschillende disciplines en naar buiten brengen van aandachtspunten en risico's.
 30. Niet aangetoond, althans niet expliciet maar meer op gevoel.
 31. Geen validatiematrix gehad maar gewoon aan de klant en SH vragen en aan mensen vragen of ze het ontwerp goed of slecht vinden en waarom.
 32. V&V methode worden meegenomen in eisenpakket maar geen aparte V&V matrix gehad.
 - 33 (75). Ja, verificatie op gevoel en niet expliciet.
 34. Allebei. Voor contracten wel top down.
 35. Ja wel mogelijk.
 36. Bij Regiotram niet
 37. Als het expliciet is dan is het herkenbaar
 38. Ja
 - 39 (81). Ja ook, decompositie om contracten te maken
 40. Overleggen, identificeren en bespreken, erkennen en afspraken maken.
 41. Bij projectbureau zaten verschillende mensen met verschillende disciplines en ervaringen en ging makkelijk.
 42. Op zich geheel, waar elke discipline op zijn eigen subsysteem
 43. Jawel, SE is expliciet maar in dit project was het niet zo gegaan. En in 1 keer goed is niet mogelijk.
 44. Lijkt wel succesvol, door open contracten meer vrijheid. SE is een overzichtelijke manier en gestructureerd werken.
 45. Ja
 46. Stappen in goede volgorde zetten. Literatuur is abstract. Relaties betrekken bij ontwerpproces. Beter V&V. Onbekendheid bij SE en moet beter.
- Alles zit wel in de SE en het is integrerend werken. Liever niet inschakelen van een SE specialist want SE moet bij alle teamleden begrepen worden dus ook pragmatisch. VDC is ook een pluspunt. Iedereen zou ook een eigen risicodossier moeten hebben naast die algemene risicomatrix.

Interview 17

- 1,2,3. MAVA, het was mijn eerste ervaring met SE en ik zat bij specificatie en scope als adviseur. Het is nu in uitvoering (DBFM).
- Bij Zaanbrug was ik als projectleider maar het project is nu in beginfase en het is ook niet zo groot.
4. Er zijn wel cursussen, stappenplan, lezingen geweest, maar ik denk niet dat het voldoende is geweest voor het toepassen van SE.

5. Ja die is er.
6. Niet apart, wensen en randvoorwaarden worden wel rekening mee gehouden.
7. Ja, met Excel, bomen met eisen gekoppeld.
8. Ja want dan kan je aan OG laten en eisen makkelijk terugvinden.
9. Ja als basis. In offerteaanvraag heb je die probleemstelling.
10. Niet 100% want niet alles is altijd SMART te formuleren. Bij kleine projecten gaat men wat pragmatisch om met SE
11. Ja dat wordt wel gedaan.
12. Onvolledige eisen, doorgevraagd. Strijdige eisen, in mijn project niet tegengekomen maar dan zouden in iRoom deze besproken worden. We doen altijd dubbelecheck voor volledigheid.
13. Wij kijken zelf of er iets mist en er gebeurt wel soms dat er iets mist. Ik denk dat SE daarbij kan helpen dat we alles meenemen.
14. Onderzoek uitvoeren en aan OG vragen en soms bij andere stakeholders.
15. Telefonisch, overleg met verslagen, sessies in iRoom.
16. OG wordt geïnformeerd over eisen en bij wijzigen van eisen worden de consequenties aangegeven.
17. Kan ik nog niet zeggen.
18. Ja, elke eis is aan een stakeholder verbonden in de gegeven kolommen maar soms heeft dat geen toegevoegde waarde (omdat de eis niet zo belangrijk is of stakeholder geen macht/interesse heeft).
19. Ja in een Excel-sheet.
20. Excellijst, database, actielijst en opmerkingenlijst.
21. Schetsontwerpen, PvE.
22. Ja altijd, een projectbeheersplan en steeds risico's actueel houden.
23. In dit project niet.
24. Geen varianten ontwikkeld hierbij.
25. Als basis van ontwerpen en om terug te kijken.
26. Nu nog niet.
27. Bij belangrijke en cruciale dingen wordt een afspraak gemaakt met de klant en deze met hem besproken.
28. Soms wel, een concept product wordt gemaakt en de resultaten besproken met de OG. Soms gebeurt dit op afstand.
29. Tekeningen, vergunningen, berekeningen, contractstukken.
30. Misschien ter verduidelijking van iets als een deelproduct.
31. Behalve bovenstaand nee.
32. Kan ik nog niet vertellen.
- 33 (MCA). Evaluatie wordt niet expliciet gedaan. Het gebeurt meer uit ervaring en expertise. We gebruiken dan soms vragenlijst en formulieren om iets te evalueren.
34. Ja de prestatie moet worden aangetoond.
35. Invullen in de eisenkolom en de OG moet checken en paraaf zetten.
36. Meer in woord en overleg en deze wordt vastgelegd in verslagen.

37. De klant doet dat door akkoord te geven (de producten worden aan hem voorgelegd en hij vindt deze goed of heeft commentaar).
38. Nee, geen aparte methoden.
39. Ja in principe wel.
40. Meestal top-down.
41. Het is logischer en ook mogelijk.
42. Niet vaak, dat gebeurt als bottom-up is gewerkt.
43. Ja, elke fase twee cycli.
44. Ja, in de boomvorm.
45. We maken wel de juiste decompositie, alleen het past niet zo goed binnen ontwerpproces.
46. Door objecten te benoemen en hun relatie te beheren hoewel het wel lastig is en met SE is het beter.
47. Samenwerking door intern overleg. SE draagt bij omdat dezelfde eisenpakket bij iedereen ligt.
48. Dat moet nog blijken maar zo ver het geheel nog centraal.
49. Ja kan wel. Door decompositiemodellen is het overzichtelijker.
50. Ja SE is zeker expliciet maar of het in een keer goed gaat, dat is wel de vraag.
51. Bepaalde elementen wel. Maar moet nog beter.
52. Ja, sommige elementen van SE zijn heel goed.
53. Alle stakeholders moeten bijdragen en er moet bereidheid zijn. SE elementen zijn op zich wel goed, alleen de invulling en doorslaan van eisen is niet altijd in orde.

Interview 18

Er is een verschil tussen praktijk en perceptie als het over SE gaat. Het gaat om smart maken van projecten, zuiverheid van de vraag en verbeteren van oplossing. Vroeger maakten we ook PvE en vraagspecificatie en eigenlijk ook verificatie en validatie maar nu is het veel fysiekeer en expliciet terwijl vroeger minder vastlegging werd.

- 1,2,3. Project N207 en het is nog in uitvoering en ik was projectleider daar.
4. Ja die is er altijd.
5. Ja, alleen die zetten we om in eisen.
6. Ja.
7. Ja zeker.
8. Ja meestal wel.
9. In het begin minder maar in contract wel.
10. Jawel.
11. Terug naar de klant en vragen wat hij wil.
12. Sommige eisen maak je tijdens het ontwerpen.
13. Door aan de klant te vragen of stakeholders.
14. Hangt af van de wens van klant. Liefst zo voeg mogelijk, VDC (Virtual Design & Construction), iRoom en op locatie.
15. Kaders worden besproken met de klant en randvoorwaarden worden gecreëerd. Zie ook

vorige vraag.

16. In beginfase is de klant meer bij betrokken dan in latere fasen.
17. Ja, eigenlijk moet bij elke proces een stakeholderanalyse komen. Bijvoorbeeld als in het begin geen tunnel zou worden gebouwd maar later toch wel dan komen ineens andere of meerdere stakeholders erbij dan in het begin.
18. Ja dat gebeurt wel.
19. Database voor eisen, i-Room, aantekeningen
20. Eisenspecificaties, risicoanalyse, schetsen, beschrijving ontwerp
21. Ja ook risicoanalyse wordt gemaakt.
22. Soms mis je wel wat maar dan ga je die ophalen. In het begin worden veel aannames gedaan. Als je echt ontwerp dan ga je vragen bij de klant of adviseur.
23. Nee, in vroegere stadia zijn er meer ontwerpen.
24. Deze worden met de klant vastgelegd met tekeningen, i-Room wordt gebruikt en eisen + ontwerp gaan hand in hand. Een ontwerper moet de eisen lezen.
25. Nee, niet alles is in specificatie en op tekeningen te zien.
26. 1 op 1 in i-Room en gesprekken.
27. Ja, met de klant en in i-Room gaat dat veel sneller. Met SE kan deze worden vastgelegd (expliciet gemaakt).
28. Verificatiematrix op basis van criteria (kosten, esthetica, comfort), raming, trade-off matrix, tekeningen, eisenprogramma en advies.
29. (Evaluatie)
Er wordt geëvalueerd in een meeting. Alle partijen moeten open staan. Als project slecht is gedaan dan wordt er veel geëvalueerd. De klant wordt gevraagd wat hij van proces vond. Als iets niet goed is dan komt het in een verslag, zogenaamde afwijkingsrapport en deze wordt meegenomen voor later.
30. Verslag en formulieren.
31. Klantonvriendelijkheidsonderzoek
32. Ja bij tenders wel. Verificatiematrix aanvinken.
33. Met VDC, gevoel creëren. Met vage eisen kunnen we niks mee en er gebeurt niet veel met SE.
34. Vroeger gebeurde het niet. Nu met VDC en voor de rest weet ik niet. Validatie gebeurt niet duidelijk apart.
35. Niet duidelijke methodes.
Deze vragen - Geen antwoorden, geen inzicht.
- Nut
36. Ja SE is expliciet. Het gaat niet in 1 keer goed. Met SE structureer je beter en ook met decomponeren. Eigenlijk gebeurde er vroeger ook zo maar nu is het explicieter.
37. Ja de doelstellingen zijn wel bereikt maar dit zeg ik meer op gevoel en niet met harde bewijzen. Door de resultaten aan het eind te vergelijken met andere projecten.
38. Ja ik zie potentie in SE en het moet veel meer en beter worden toegepast.
39. Toepassen van VDC in SE.

Interview 19

- 1,2,3. MAVA, DBFM, en ik zit in contractmanagement team en operations management.
Het is nu tijdens de piek van het ontwerp.
4. Ja, vooral in voorgaande projecten veel geleerd.
5. Ja, systeem decompositie en procesdecompositie ook.
6. Nee, stakeholderanalyse uitgevoerd maar niet opgeschreven (niet alles expliciet) waarom die stakeholders die eisen/wensen hadden. Wensen zijn geïntegreerd in eisenlijst.
7. Met eisen wel, systeemeisen, proceseisen maar geen aparte voor wensen en randvoorwaarden.
8. Ja, voor eisen zeker is er structuur nodig.
9. Ja, in projectplan maar probleem is abstract. OG moet zeggen wat opgelost moet worden.
10. Nee, eerst functioneel opgesteld maar uiteindelijk wel SMART.
11. Onvoldoende, als we niks horen van ON dan blijft het zo als het is.
12. Gesprek met OG voeren en dan aanpassen en sommige eisen vervallen.
13. Niet voldoende, ON moet het ophalen.
14. Gesprekken met OG en de team.
15. Overleggen maar ook via telefoon en email.
16. Door gesprekken, dan geformaliseerd met contractoverleg.
17. Ja wel, ver in ontwerpproces en laat. Beginnend met SE en dan onbewust geen SE.
18. Ja, eisen kennen per stakeholder.
19. Ja, ON maakt werkpakket voor een object. Maar geen raakvlakeisen worden opgesteld.
20. Database (Relatics), checklists.
21. Eisenanalyse, stakeholderanalyse processen, deze twee wordt als decompositie gemaakt door ON.
In contract komen systeemeisen en proceseisen die eisenanalyse vormen.
Soms ook schetsen als iets niet duidelijk is.
22. Ja risico's nemen we mee.
23. Dat doet ON (Stanley zelf heeft geen inzicht daarop), maar op zich wel.
24. Nee, veel werk door ON en die heeft soms duidelijke keuzes al.
25. Door ze SMART maken en kijken welke alternatieven heb je maar er wordt in ontwerpfase te weinig gekeken naar eisen en wensen.
26. Nee niet voldoende. ON kan niet weten welke mogelijkheden er zijn omdat niet alle opties altijd beschikbaar worden. ON heeft andere belangen
27. Soms door te praten over opties.
28. In ontwerppnota's worden onderbouwing vastgelegd.
29. Moet aan eisen voldoen, tekeningen, berekeningen, verificatiematrix.
30. Geen antwoord.
31. Ja, interne afwegingsdocumenten, werkplan, uitvoeringsontwerp, vergunningen.
32. Informatie mist voor onderbouwing verificatie.
33. Structuur wordt gemist, analyseproces mist en trade-offs missen, verificatie en validatie ook niet compleet.

Vragen over evaluatie (Trade-offs) en niet meetbare criteria, geen antwoord.

34. Ja, ze worden meegenomen in managementspecificaties en systeemspecificaties.
35. Niet gebeurd!
36. Op één moment.
37. Wanneer ON een belangrijke keuze moet maken. MCA wordt niet goed gemaakt omdat ON intern al keuzes heeft gemaakt (uit financieel oogpunt).
38. Nee
39. Relatics, Think Project
40. Nee
41. Ja dat wel
42. Verificatiematrix nalopen terwijl verificatie methoden niet duidelijk is.
43. Met pragmatische oplossingen en met OG praten.
44. Niet gedaan, geen duidelijk beeld over validatie. ON verifieert en dat is goed en voldoende.
45. Nee, heel soms is er verificatie- en validatiemethode.
46. Nee
47. Bottom-up, traditioneel.
48. Absoluut mogelijk.
49. Niet vaak herzien, wel soms.
50. Soms wel.
51. Ja maar weinig. Er is geen validatie voor decompositie. Het is meer oplossingsgericht.
52. Raakvlakken, door ontwerpmanager maar vaak weinig in praktijk.
53. D.m.v. ontwerpoverleggen.
54. Substelsysteem
55. Jawel, maar eigen belang komt eerst in praktijk.
56. Ja, het is expliciet. Ja, als je vanaf het begin alles goed doet worden dingen beheersbaar en scope wordt beter en daardoor geeft SE rust.
57. Nee, nog niet alle punten bereikt. Iedereen moet het doen en hoe meer SE wordt toegepast hoe beter.
58. Ja, scope wordt helder gemaakt en kans op falen wordt kleiner.
59. Stakeholderanalyse moet beter namelijk eisen koppelen aan waarom die eisen bestaan. Raakvlakeisen moeten beter, validatie kan beter, raakvlakmanagement, trade-offs, risicomanagement.

Interview 20

- 1,2,3. Project A2 Hooggelegen bij Utrecht en is bijna afgerond, Alliantie contract, als adviseur en systems engineer.
4. Ja, workshops, cursussen en tijdens project ook veel geleerd.
5. Ja in een database
6. Geen wensen en randvoorwaarden zitten in contract.
7. Voor eisen wel
8. Ja veel nuttig
9. Probleemstelling waren heel duidelijk
10. Meestal wel maar niet alle eisen kunnen SMART. Topeisen kunnen niet SMART.
11. Ja, dat is een procedure bij eisenanalyse.
12. Er is een goedkeuringsproces, bespreken met ontwerper en technische manager en terugkoppelen naar contract en zo nodig de eisen verbeteren/wijzigen. Iteratieslagen gebeuren dus.
13. Niet lang goed genoeg of incompleet en soms bleek dat het anders moest.
14. Uit informatieanalyse en alliantie managementteam.
15. Via OG-lijn en omgevingsmanager en daarna overleg.
16. Bij Alliantie is iedereen automatisch bij betrokken maar vooral bij eisenvalidatie was de OG veel betrokken.
17. Ja, in Relatics
18. Relatics als database, formats voor trade-offs.
19. Eisenpakket, verificatieplannen.
20. Risico matrix continue geüpdatet en ook gebruikt bij trade-offs.
21. Wel voldoende
22. Ja, wel gedaan, en UO op onderdelen maar met name DO.
23. Eisen zijn vastgelegd in verificatieplannen. Ontwerper leest eisen en verificatieplannen.
25. Ja in algemeen wel.
26. Alliantie, dat betekent dat veel samenwerking is tussen alle partijen, eerst interne reviews en dan extern bespreken.
27. Ja, variantenrapporten en in trade-offs en ontwerpnota's vastgelegd.
28. Ontwerpnota, verificatieplan, berekening/tekening.
29. Alles wat vereist is wordt ook gemaakt.
30. Memo's, overlegverslagen, afspraken.
31. Ja wel voldoende.
32. Meetbaar maken met tijd en geld.
33. Ja.
34. Met kleuren naar prioriteit. Per discipline is het anders, expertise en samen met klant.
35. Ja in iedere fase per ontwerp pakket.
36. Was al betrokken in Alliantievorm
37. RAMS-methode, Risicomanagement formats
38. Excel

39. Nee
40. Ja, dat moet
41. Hij leidt ze af, door SMART te maken, expliciet vastleggen met bewijsstukken.
42. Sub-analyse gedaan, expertanalyse, geen risico en dus voldoende specifiek maken.
43. Ontwerpreviews per werkpakket, stakeholders uitgenodigd en presentatie gegeven over proces en rol van die stakeholder en dan inhoudelijk dingen besproken. Stakeholder maakte opmerkingen en die werden dus meegenomen in proces. De bijeenkomsten werden georganiseerd en klant toetste de ontwerpen en daarmee keurde ze deze goed.
44. Per eis hadden we een verificatiemethode en soms ook validatiemethoden. Expertreviews leidden ook tot validatiemethoden en validaties.
45. Ja, niet in UO maar wel in DO en VO.
46. Top down.
47. Top-down is noodzakelijk want bij bottom-up vergeet je veel.
48. Wel discussies gevoerd op onderdelen. Soms gebeuren er vertragingen als de klant iets wijzigt.
49. Ja soms wel maar beperkt.
50. Ja van systeemonderdelen, Risicobomen, Requirements breakdown, Work Breakdowns.
50. Raakvlakken zijn benoemd en deze werden beheerst door raakvlakeisen op te stellen door minimaal twee mensen.
51. Raakvlakmanager zorgde voor die samenwerkingen vooral.
52. Raakvlakken bijhouden, reviews intern bespreken met elkaar.
53. Er wordt geredeneerd vanuit geheel maar focus is op subsystemen.
54. Ja, decomponeren en raakvlakanalyse uitvoeren en contact met alle disciplines houden.
55. Ja, en die explicieteit levert nut op. In een keer goed gaan kan niet.
56. Klantvraag en gestructureerd werken zijn wel bereikt. Effectiviteit en efficiency zijn in die zin bereikt dat heel veel risico's worden van te voren benoemd en raakvlakken beter beheert, als het goed gebeurt, dan levert het tijd en geld op.
57. Ja en niveau 4 en 5 van volwassenheid kan nog breekt worden.
58. Voor projectmanagement moet breder gekeken worden en ISO 15288 beter worden toegepast. Er zijn ook andere zaken dan ontwerpproces en SE gaat over gehele zaken.
59. Een informatiemanagement (voor raakvlakken en communicaties)
Bekendheid SE bij iedereen moet gevorderd worden, standaardiseren. Meer aandacht voor validatie en communicatie met alle stakeholders zijn de punten die verbeterd kunnen worden.